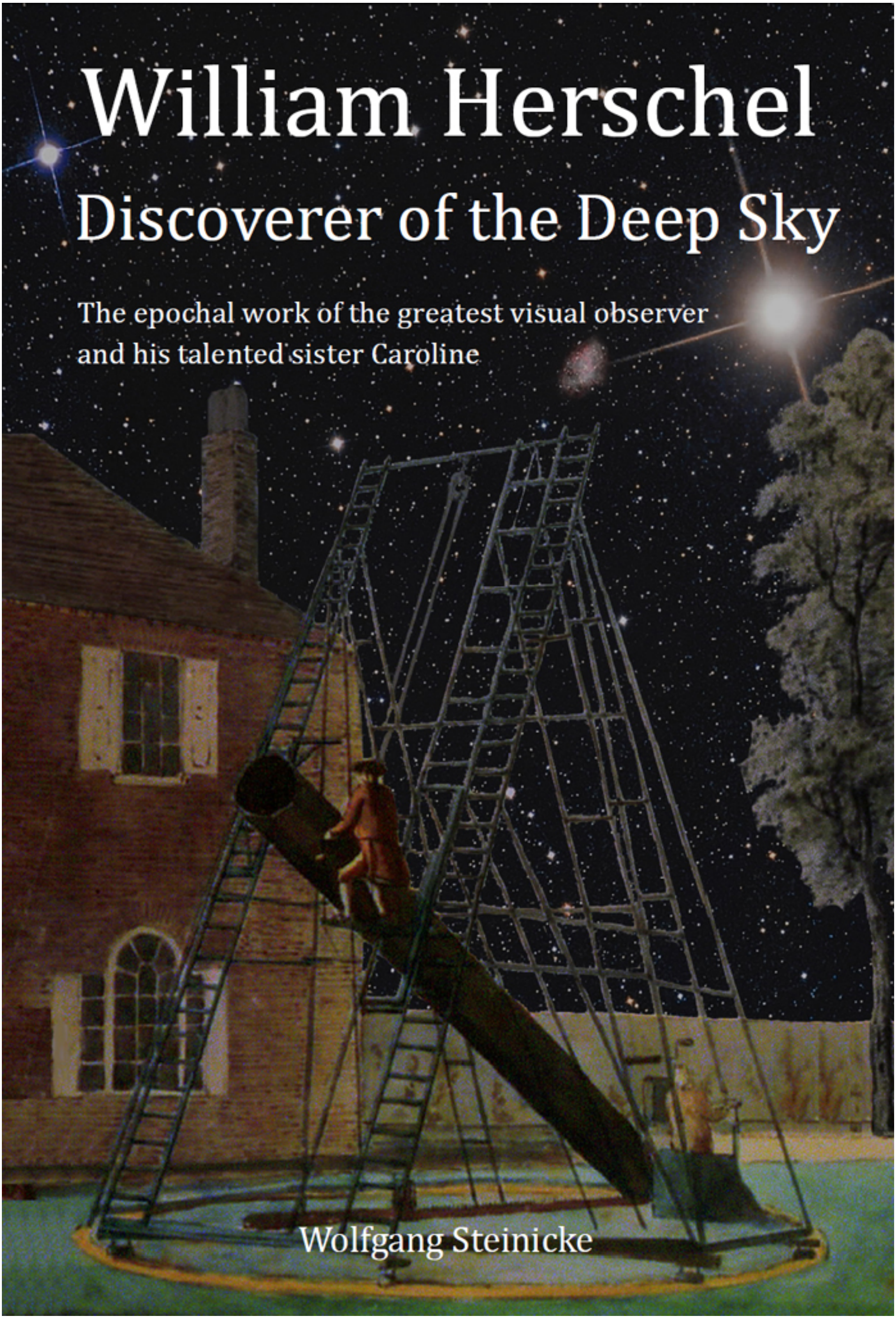

William Herschel
Discoverer of the Deep Sky
The epochal work of the greatest visual observer
and his talented sister Caroline
Wolfgang Steinicke

A contribution to the bicentenary of William Herschel's death in 2022

To my wife Gisela

William Herschel (1738–1822), drawn by Henri Grévedon in 1828.

Content

PREFACE
INTRODUCTION
1. EARLY OBSERVATIONS
1.1. The first nights: Orion Nebula and two double stars
1.2. Basic sources, first telescopes and observing records
1.2.1. Herschel's library
1.2.2. Herschel's early document series
1.2.3. The mysterious first 'star review' and larger reflectors
1.3. The second star review: the 7-foot reflector at work
1.3.1. The number of double stars grows
1.3.2. The coincidental but inevitable discovery of Uranus
1.4. The third star review: a flood of new double stars
1.4.1. The *Atlas Coelestis* and Flamsteed numbers
1.4.2. Mayer's double star catalogue and the move to Datchet
1.5. Herschel's two catalogues of double stars
1.5.1. The first catalogue
1.5.2. The second catalogue
1.6. Red and variable stars
1.6.1. Herschel's 'garnet stars'
1.6.2. Observing 'periodical stars'
1.7. Messier objects
1.8. William's new nebulae and star clusters
1.9. Caroline's observations of nebulae and star clusters
2. THE GREAT SWEEP CAMPAIGN
2.1. Starting the sweeps in 1783

2.1.1. A new telescope
2.1.2. The first 41 sweeps
2.1.3. A new sweeping method and Caroline's participation
2.1.4. Book-keeping: sweep records
2.1.5. Sidereal time and Caroline's first zone catalogue of Flamsteed stars
2.1.6. The first deep-sky catalogue and a preliminary classification
2.1.7. Summary of the 1783 sweeps
2.2. The record year 1784
2.2.1. Observing on a chair and the M 49 drama
2.2.2. First quarter – a season for galaxies, sketches and new devices
2.2.3. The paper on the 'construction of the heavens'
2.2.4. Second quarter – hunting the 'stratum of Coma Berenices'
2.2.5. Third quarter – Barthélemy Faujas de Saint-Font visiting Datchet
2.2.6. Fourth quarter – an expedition to the east and problems with M 20 and M 8
2.2.7. Summary of 1784
2.3. 1785 – another busy year
2.3.1. A new equinox and Herschel's second paper on the 'construction of the heavens'
2.3.2. A competent visitor at Datchet: Jean Hyacinthe de Magellan
2.3.3. An expedition to the north, the monster sweep 396 and the Coma Cluster
2.3.4. More galaxy clusters, uncatalogued objects and the move to Clay Hall
2.3.5. Messier objects and a 'demonstration sweep'
2.3.6. Summary for 1785
2.4. Herschel's first catalogue of nebulae and star clusters
2.4.1. The arduous way to its publication
2.4.2. Structure, content and data quality
2.5. Observations in 1786 – the move to Slough and

Caroline's first Comet
2.5.1. The first quarter of 1786: uncatalogued objects and stars
2.5.2. Move to Slough and Caroline's second zone catalogue of Flamsteed stars
2.5.3. William's absence and Caroline's success – the 1st comet
2.5.4. The 20-ft as a front-view reflector
2.5.5. Summary of 1786
2.6. Observations in 1787 – satellites and first light of a giant
2.6.1. Two moons of Uranus
2.6.2. Enceladus and first light for the 40-feet reflector
2.6.3. Further observations of nebulae and clusters, reaching the zenith
2.6.4. Summary of 1787
2.7. Observations in 1788–89
2.7.1. Sweeps, family affairs and Caroline's 2nd comet
2.7.2. Sweeping with the 20- and the 40-ft
2.7.3. Herschel's second catalogue of nebulae and star clusters
2.7.4. Summary of 1788–89
2.8. Observations in 1790–91
2.8.1. Caroline's 3rd and 4th comet, William's 'star with an atmosphere'
2.8.2. Herschel's 'nebulous stars' and planetary nebulae
2.8.3. Caroline's 'large sweeper' and the 5th comet
2.8.4. Summary of 1790–91
2.9. Observations in 1792–94, before sweeping was halted for three years
2.9.1. More sweeps, a 40-ft discovery and Caroline's 6th comet
2.9.2. Summary of 1792–94
3. FINAL SWEEPS AND THE LATER YEARS
3.1. Stellar magnitudes, the 7th comet and Caroline's first publication

3.2. Restart of sweeping
3.2.1. The 25-ft reflector and Caroline's 8th comet
3.2.2. A revolutionary reflector, the 'X-foot'
3.2.3. Summary of 1795–99
3.3. A new century
3.3.1. The power of penetrating into space
3.3.2. The mysterious northern sweep 1096
3.3.3. The curious case of M 81/82 and the first asteroids
3.3.4. The last sweeps
3.3.5. Summary of 1800–02
3.4. The final catalogue of nebulae and star clusters
3.4.1. Three missing objects
3.4.2. Dates of the three catalogues and the eight additional non-stellar objects
3.5. The post-sweeping era: 1803–1822
3.5.1. A revival of Messier objects and Herschel's new favourite, the 'X-foot'
3.5.2. The last decade: William's death and Caroline's return to Hanover
4. THE STELLAR SYSTEM AND THE NATURE OF NEBULAE AND STAR CLUSTERS
4.1. 'Star gages' and the structure of the Milky Way
4.1.1. The first paper on the 'Construction of the Heavens' (1784)
4.1.2. The second paper on the 'Construction of the Heavens' (1785)
4.1.3. Further gages and the paper of 1802
4.1.4. The death of Herschel's section
4.1.5. 'Vacant places' and the famous 'hole in Scorpius'
4.1.6. John Herschel's star counts and the fate of his father's stratum
4.2. Herschel's interpretation of the observational data
4.2.1. The paper of 1811: sketches and 52 regions of 'extensive diffused nebulosity'
4.2.3. The papers of 1817 and 1818 – a matter of 'profundity'
4.2.2. The paper of 1814: nebulous stars, star

clusters and more sketches
5. MODERN ANALYSIS OF HERSCHEL'S DATA
5.1. Sweep method and its yield
5.1.1. Relevant documents, digitization and important questions
5.1.2. Sky coverage and Herschel's success rate
5.2. The content of Herschel's deep-sky catalogues and sweep statistics
5.2.1. Reference stars and Caroline's list of all observed stars
5.2.2. Catalogued, uncatalogued and missed objects
5.2.3. Brightness, size, multiple objects and constellations
5.2.4. Observing sites, viewing modes, moonlight and weather
5.3. Messier objects, telescopes and the Solar System
6. REVISIONS OF HERSCHEL'S CATALOGUES
6.1. Caroline's *Zone Catalogue* – most famous but widely unknown
6.2. John Herschel's Slough/Cape observations and the work of Lord Rosse
6.3. Auwers' revision, d'Arrest's observations and position accuracy
6.4. Dreyer's *Scientific Papers*, further observations and a modern revision
EPILOGUE
APPENDIX
Visitors
Herschel's journeys
Timeline
INDEX
Persons
Objects
Nebulae and star clusters: names
Nebulae and star clusters: catalogues
Stars: double
Stars: name
Stars: constellation

Stars: catalogues
Solar System
Subjects
General
Telescopes
Institutions and sites
Sources, catalogues
Abbreviations
REFERENCES
Literature
Internet sources
ABOUT THE AUTHOR

Preface

My enthusiasm for deep-sky objects like galaxies, nebulae and star clusters goes back a long way – they were the targets of my first telescopic explorations of the night sky, visible from Germany. Of course, I came across John Louis Emil Dreyer's famous *New General Catalogue* (NGC), published in 1888. It is mainly based on the observational work of the German-born astronomer William Herschel and his son John.

Later, I started a study of the historical background of the NGC to reveal the discoverers, dates, instruments, methods and places related to its 7840 entries. The results were published in 2010 as a 650-page book by Cambridge University Press, titled *Observing and Cataloguing Nebulae and Star Clusters: From Herschel to Dreyer's New General Catalogue*.

After examining the NGC, it was quite natural to focus on William Herschel. Dreyer did the same, when he published the monumental *Scientific Papers of Sir William Herschel* in 1912. The two volumes give a lot of insight into the work of the fascinating man with many talents. Herschel was the central person in the instrumental, observational and theoretical development of deep-sky astronomy. Starting with a search for double stars, the self-taught astronomer was always on the lookout for new objects that came into view in his superior telescopes, much like the early Earth explorers who entered Terra Incognita. William's epochal 'sweep campaign', made in 1783–1802 to find non-stellar objects and supported by his talented sister Caroline, covered almost the entire sky visible from southern England.

All available documents and publications were consulted to study the work of the Herschels. Of course, my long-time telescopic experience was crucial to understanding the observational data. The analysis of the huge amount of information took many years. The results are presented in this book. In admiration and honour of the greatest visual observer of all time, it is my personal contribution to the 200th anniversary of William Herschel's death, which will be

celebrated on 25 August 2022.

I apologize that the book is largely a series of facts, which can be tiresome at times. In order to present the historical and astronomical dimension of the topic in its entirety, it was hardly possible to process the data in any other way. It is therefore also aimed at observers who want to understand Herschel's results.

This work would not have been possible without the support of my wife Gisela. In particular, she was a knowledgeable companion on many astronomical tours and aide with my visual observations. My research was supported by famous institutions, like the *Royal Society*, the *Royal Astronomical Society*, the *Herschel Society* and the *Herschel Museum*, Bath. My biggest thanks go to Michael Hoskin for his long friendship and our many discussions. I must also thank George Sibley for his famous documentary film on Herschel that I was able to contribute to. Other supporters include Courtney Seligman, Owen Brazell, Wayne Orchiston, Tony Symes, Roger Ceragioli, Clifford Cunningham, Steven Dick, Simon Schaffer, Ian Ridpath, Emily Winterburn and Woody Sullivan.

Wolfgang Steinicke, October 2021

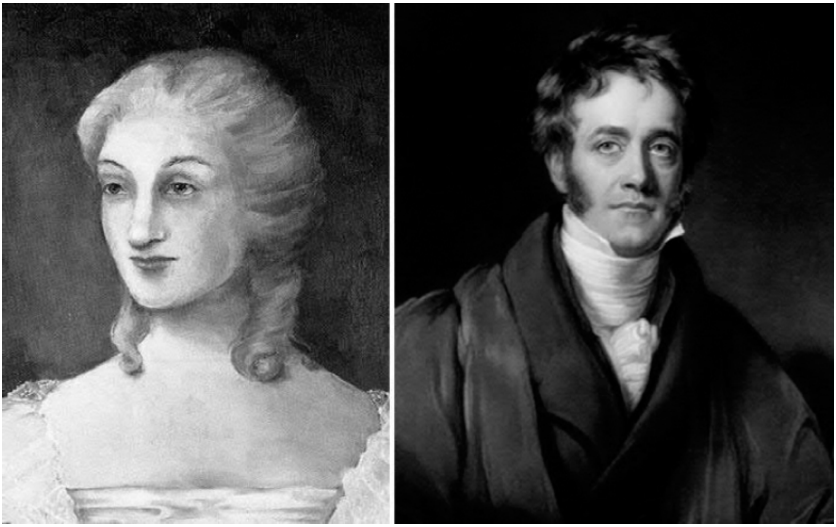
Introduction

When exploring the heavens, the German-born William Herschel entered new land. Equipped with the best telescopes of the time, built by himself, and open to revolutionary ideas, he became the leading astronomer in the late 18th and early 19th centuries. Recognising his privileged position, Herschel wasted no time in using the full capacity of his resources. He not only was the master of observational astronomy, but learned all that was needed about mechanics, optics, physics and applied mathematics. When necessary, he created new methods and devices. This all was done for one great task: to reveal the ‘construction of the heavens’, the theme of his life.

William Herschel first studied the building blocks: celestial objects in all their variety. He started with a search for double stars, detectable in his fine 7-foot Newtonian reflector. In 1781, that task yielded an unexpected epochal discovery: Uranus. Two years later, his focus turned to nebulae and star clusters. To find such non-stellar objects, he developed a systematic method to survey the sky, called ‘sweeping’. Herschel became a natural historian of the heavens. With an ingenious 20-foot reflector, he finally discovered about 2500 objects between 1783 and 1802. In this mission, he was supported by his talented sister Caroline. She not only prepared the nightly observation but was also responsible for recording the data, their cataloguing, evaluation and final publication.

Over the years, Caroline grew to be a respected scientist in her own right. She observed with small telescopes built by her brother, and soon found some objects, not already catalogued by Charles Messier. However, her greatest yield was obtained in the Solar System: eight comets – an unmatched mark for years! Moreover, her thorough examination of the leading British star catalogue led to a book, published in 1798 by the *Royal Society*. In the 1820s, Caroline revised William’s three catalogues of nebulae and star clusters. The result, known as the *Zone Catalogue*, was an important source for her nephew John, when he was re-observing the Herschel objects at Slough. For this work, Caroline was rewarded with the *Gold Medal*

of the *Astronomical Society of London* in 1828.



Caroline Herschel (1750–1848) and her nephew John Herschel (1792–1871).

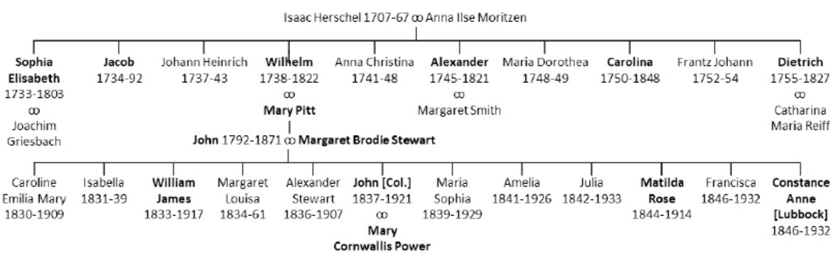
William Herschel's sweeps included extensive star counts ('gages'). With these data, he determined the distribution of stars in the stellar system surrounding the Sun. From their numbers, he finally derived a spatial view of the Milky Way for a particular section, revealing a flattened, branched 'stratum' of stars. He was the first to prove theoretical views by quantitative observations, creating the field of 'stellar statistics'.

Herschel's work was very influential, leading to the view among contemporary astronomers that there was nothing left to discover in the sky. Indeed, concerning double stars, nebulae and star clusters, there was no competition. The observer who found the last non-stellar object before the start of his observations was Pierre Méchain, in April 1782. Herschel's observational and instrumental dominance lasted until his death in 1822. The first person to discover a non-stellar object after him was his son John, in August 1823.

John Herschel was the only person, willing and able to do a comparable work. Equipped with a new 20-foot reflector in the

style of his father, he entered a stellar Terra Incognita – the southern sky. John discovered a large number of objects. However, he did not only rely on cataloguing, but also took the opportunity to combine the data for both hemispheres to draw a picture of the entire sky. It is quite natural that some of William's ideas were modified or even rejected by the extended view available to his son. But this in no way diminished the achievement of this exceptional, multi-talented astronomer.

William Herschel was part of a great family (the scheme below shows the relevant persons. Mary Cornwallis (writing as 'Mrs. John Herschel') was the author of the *Memoir and Correspondence of Caroline Herschel*, written in 1876. Her book is one of two on the family history written by its members. The other is due to Constance Anne Lubbock, John Herschel's last child and a scientist herself: *The Herschel Chronicle*, published in 1933. She wrote: "The engaging frankness with which [William] Herschel was ever ready to impact his ideas and speculations (inhabited Moon) in conversation was one part of his charm in social intercourse, but he had to learn that such frankness might be prejudicial to his reputation". Due to his intellectual power, diligence and enthusiasm, William Herschel would undoubtedly have been a master in any scientific discipline. His great musical skill and creativity was transformed into astronomy.

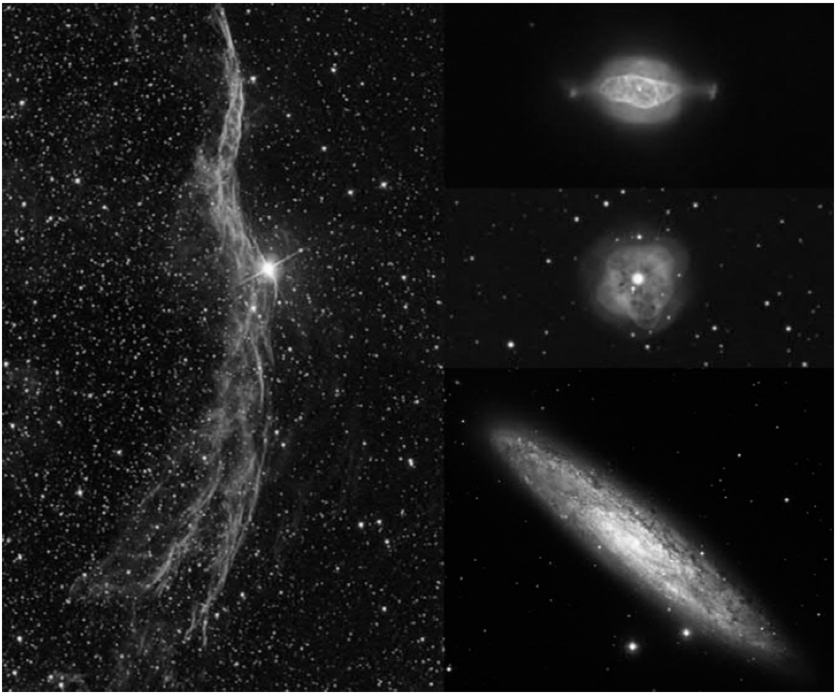


The main persons of the Herschel family. The bold ones are mentioned in the text.

This book concentrates on the observational part of William Herschel's work. Although Caroline, and later John, play an essential role, family affairs are barely treated. The main focus is on science, both practical and theoretical. The first aspect includes visual observations, telescopes and devices, sites, observing

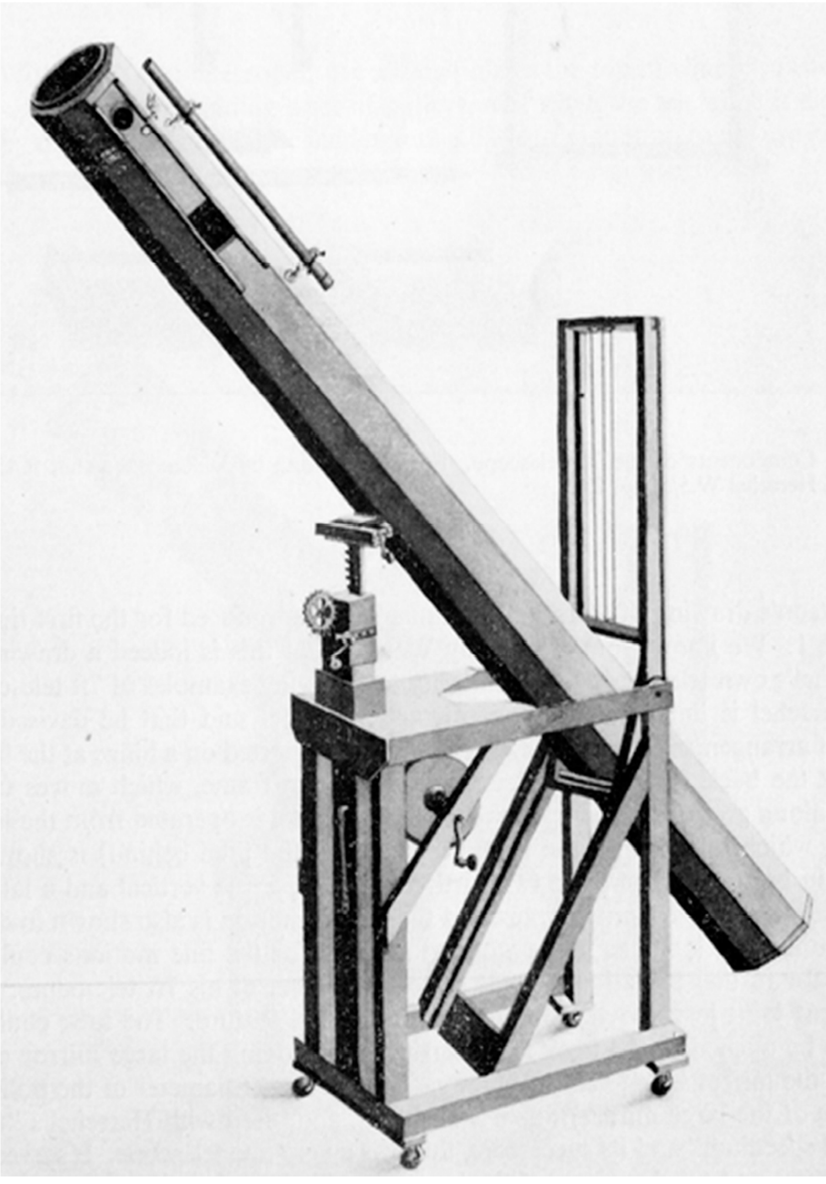
methods, data recording and evaluation and the publication of the results. Various persons were involved. The second aspect concerns about William's ideas on the nature and evolution of cosmic objects. The main focus is on nebulae, star clusters, double stars, red stars and variable stars. Of course, Solar System objects are also treated. The sources are original documents and the published papers. All were analysed with modern digital tools, yielding many new insights. The results are presented in six chapters. The first three are arranged chronologically, starting with Herschel's observations at Bath using small instruments. In that period, Uranus was found. The second chapter is central, treating the epochal sweep campaign. Chapter 3 describes the final sweeps, made after a break of three years, and the late period, filled with observations of stars, Messier and Solar System objects. The last chapters analyse the observations. They start with Herschel's revolutionary ideas about the structure of the stellar system (Milky Way). Chapter 5 presents a modern analysis of the methods and observational data. It shows, for the first time, the sky coverage of all sweeps and the number and distribution of discovered non-stellar objects. The last chapter treats revisions of the three Herschel catalogues of non-stellar objects, such as those of Caroline, John Herschel, and Dreyer. Finally, a modern version made by the author is treated. It clarifies the identity of the observed objects and also presents uncatalogued finds. 1015 of William Herschel's nebulae and star clusters and 84 of his double stars are mentioned in this book. The epilogue briefly treats his legacy, presenting a collection of book titles. The appendix describes the results of an examination of the people, visiting the Herschels. Further, an overview of William's journeys is given. A timeline covers the main events between 1774 and 1828. The index lists 296 persons and a large number of objects and subjects. Finally, 308 references are given.

Images of deep-sky objects are from the *Digitized Sky Survey* (DSS) or the *Sloan Digital Sky Survey* (SDSS). Star charts are based on *Guide 9.1*. Images of persons, places or institutions are from the author's archive. All modern graphics are made by the author.



Famous discoveries: William's Veil Nebula NGC 6960 in Cygnus (left), the planetaries NGC 7009 (Saturn Nebula) in Aquarius and NGC 1514 in Taurus (top/middle right) and Caroline's Sculptor Galaxy NGC 253 (bottom right).

1. Early observations



William's career as the greatest visual observer of all time started in

May 1773, when he was already 34 years old.[1] Living at 7 New King Street in Bath, his sister Caroline had joined him about eight months before.[2] The early phase of the astronomical life of the famous siblings is treated in this chapter. Inspired by scientific books, he learned to build telescopes and was introduced to interesting objects. With small instruments William soon viewed planets, stars and a few nebulae and star clusters. Due to the accidental discovery of double stars, he performed so-called ‘star reviews’ to find more examples, mainly done with his standard 7-ft reflector. He eventually published two catalogues of double stars. As a by-product of his systematic observations guided by the best star charts, Uranus was discovered in March 1781. Other finds were remarkable ‘garnet stars’. In August 1782, the Herschels moved to Datchet near Windsor Castle, where William focused on other targets: Messier objects. In the meantime, he had already discovered some new nebulae and star clusters. In this matter, however, he soon got competition – from his talented sister. Caroline studied the sky with small instruments built by her brother. In 1782, at the age of 32, she made a first discovery.

1.1. The first nights: Orion Nebula and two double stars

When observations began in spring 1774, William and Caroline Herschel lived at 7 New King Street. It was the starting point of a real Bath odyssey, as it wasn’t long before they moved to a place near Walcot Turnpike.[3] In September 1777, the siblings returned to New King Street for two years (now at No. 19).

Figure 1-1: Herschel’s workshop at 19 New King Street, Bath.

The house had a long, narrow garden. William’s workshop (Figure 1-1), located in the basement near the kitchen, was a busy place – not always to the joy of Caroline! Then they moved to 5 River Street, close to the site of the *Bath Philosophical Society*. Because there was no garden, Herschel had to observe in front of the house, practically in the street. Occasionally passers-by were allowed to look through the telescope.[4] In early March 1781, the sibling’s returned to 19 New King Street.[5] Their Bath odyssey finally ended in August 1782, when they left the city and moved to Datchet near Windsor, about 100 miles east.

Herschel’s first regular telescope was a 5.5-foot Newtonian reflector of 4.5 inches aperture, constructed in 1773/74.[6] It was easy to point the respectable instrument at naked-eye objects. The first observation, recorded in his *Journal No. 1*, is dated Tuesday, 1 March 1774 (Figure 1-2).[7]

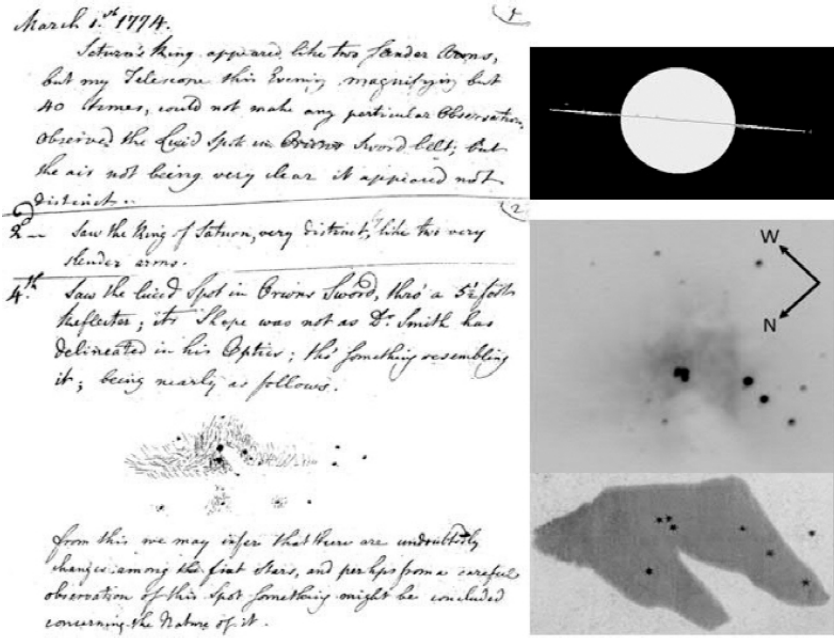


Figure 1-2: Left: the first entries in Herschel's *Journal No. 1*; they concern Saturn, seen nearly edge-on, and the Orion Nebula. Herschel's first sketch of the bright nebula was made on 4 March 1774. Right: a modern image (deliberately not very good, to have a comparison) and Huygens' sketch of 1656.

The target was Saturn, located near β Vir:[8] "Saturn's ring appeared like two slender arms, but my telescope this evening magnifying but 40 times, could not make any particular observation." The ring was seen nearly edge-on. However, the second entry is more interesting: "Observed the Lucid Spot in Orion's Sword belt; but the air not being very clear it appeared not distinct." Three days later, the object appeared much better. Herschel added a sketch and compared it with Huygens' 1656 drawing, made with a refractor of 23 feet focal length and reproduced by Smith.[9] He wrote:

Saw the Lucid Spot in Orion's Sword, thro' a 5½ foot reflector; its Shape was not as Dr Smith has delineated in his Optics; tho' something resembling it; being nearly as follows. From this we may infer that there are undoubtedly changes among the fixt stars, and perhaps from a careful observation of this Spot something might be

concluded concerning the Nature of it.

On 9 April, a third observation followed: "Observed the Lucid Spot in Orion's Sword had a very distinct view of it but day light being too strong yet, could not make so good remarks as intended. Saw now very plainly that the star to the western side was divided into three stars very close together which before I had only taken for one, and marked as such."

Due to the morning twilight, the observation of the nebulous mass brought nothing new. However, Herschel noticed that the central star θ Ori was actually a trio.[10] But this was not his first non-singular object. Earlier this night he had noted: "Observed the last but one in Ursa Majoris' tail which is a double star, and found when I magnified 211 times that it appeared very plainly to be double; being thew separated nearly (as one might say) a couple of inches the lower being considerably larger than the other."[11] The pair is Mizar (ζ UMa), the components of 2.3 and 3.9 mag are separated by 14".[12] This is Herschel's first double star that he did not know of before.

1.2. Basic sources, first telescopes and observing records

1.2.1. Herschel's library

William Herschel had long been connected to science. His very first documented astronomical observations were made in February 1766: an "Observation of Venus", seen from Wheatley (Doncaster) on the 19th, and an "Eclipse of the Moon" at Kirby Hill on the 24th. Both events are written down in his 'Memorandums from which an historical account of my life may be drawn'.[13]

In 1773, though still primarily concerned with music, Herschel began to acquire relevant books on optics and astronomy. They formed the basis of his knowledge of astronomy and telescopes. In his *Memorandum* we read for 10 May 1773:[14] "Bought a book on astronomy and one of astronomical tables." He purchased *A Compleat System of Opticks*, a 3-volume book, published 1738 by

Robert Smith, and *Astronomy explained upon Sir Isaac Newton's principles* by James Ferguson (1756); see Figure 1-3.[15] It is possible that Herschel met Ferguson, who gave popular lectures in nearby Bristol about that time. Both publications treat stars and non-stellar objects – targets that fascinated him all his life. Smith's book mainly was a manual for building telescopes. Herschel started with the construction of small refractors and then changed to reflectors with a metal mirrors made of an alloy of copper and tin, commonly known as 'speculum'.[16] He built the telescope tubes out of cocus wood, a type of ebony which was often used for musical instruments.

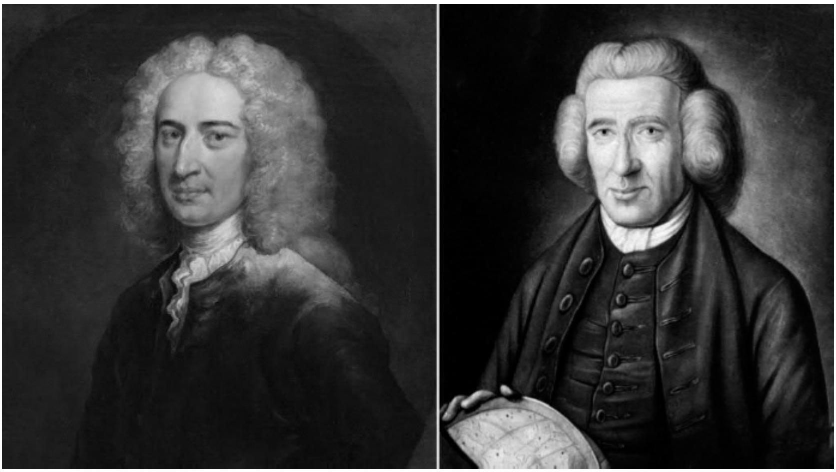


Figure 1-3: The English mathematician Robert Smith (1689–1768) and the Scottish astronomer James Ferguson (1710–1776) influenced Herschel in his early astronomical career.

There is a report about Herschel's early work on telescopes in Bath:[17]

In the spring of the year 1773, I began to provide myself with materials for astronomical purposes. The 19th of April I bought an Hadley quadrant, and soon after Ferguson's Astronomy. In May I produced some short object glasses and had tubes made for them, beginning with a 4 feet one of the Huyghenian construction [refractor]. With this I began to look at the planets and stars. It magnified 40 times. In the next place I attempted a 12 feet one and

contrived a stand for it. I saw Jupiter and its satellites with it. After this I made a 15 feet and also a thirty feet refractor; and observed with them. The great trouble occasioned by such long tubes, which I found it almost impossible to manage, induced me to turn my thoughts to reflectors, and about the 8th of September I hired a two feet Gregorian one. This was so much more convenient than my long glasses that I soon resolved to try whether I could not make myself such another, with the assistance of Dr. Smith's popular treatise on optics. […] About the 21st of October I had some mirrors cast for a two-feet reflector. […] In the beginning of November I had other mirrors cast; among them was one intended for a 5½ feet Gregorian reflector. […] In the beginning of January 1774, I contrived to put my 5½ feet mirror into a square wooden tube, intending to be used in the Gregorian way; but here I met with some difficulty in the adjustment […] I postponed the execution of the Gregorian construction to another time and had recourse to the Newtonian, which seemed to be less complicated.[18]

In addition to optics, Smith's book also introduced the budding astronomer to a bit of what was known at the time about the nature of the heavens. Chapter 7 of Smith's second volume, titled 'Telescopic Discoveries in the Fix'd Stars'[19], mentions six 'lucid spots' (see Table 1-1). They had already been described by Edmond Halley.[20] For one, the Orion Nebula, a sketch is given, made by Christiaan Huygens in 1656 (Figure 1-4).[21] This nebula would play a significant role in helping to shape Herschel's views about the nature and evolution of nebulae and star clusters.

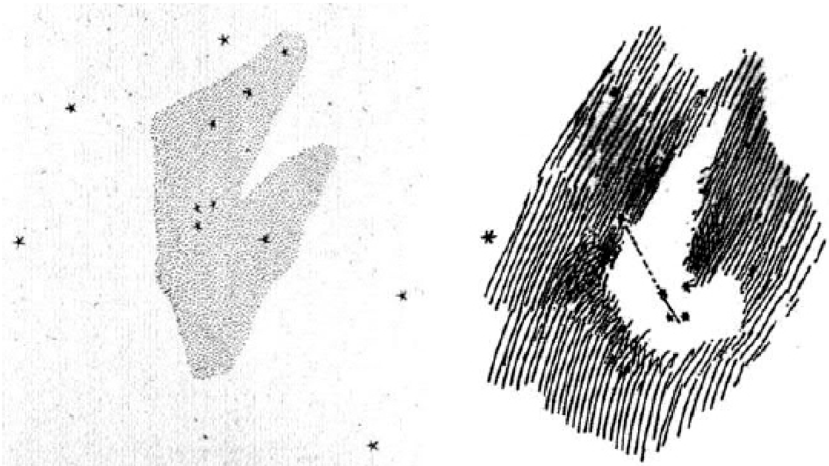


Figure 1-4: Huygens' two sketches of the Orion Nebula.[22] Left: The first, reproduced by Smith, was made in 1656 with a 23-foot refractor of 4 inches aperture; three stars in the centre are shown. Right: All four stars of the Trapezium were eventually seen in 1696 with the monstrous 44.5-foot 'air' refractor.

Ferguson also mentions deep-sky objects.[23] The chapter 'Of the fixed Stars'[24] lists 13 'Lucid spots' and 'Cloudy stars'. In addition to five from Halley, another five are due to Ptolemy[25]; three are open clusters: Praesepe (M 44) in Cancer, M 7 in Scorpius (Ptolemy's Cluster) and the Double Cluster in Perseus. Further, we have the pair ν^1 / ν^2 Sgr (Ptolemy's Eye of Sagittarius)[26] and the trio around λ Ori (Meissa). Ferguson also mentions two objects; seen by John Flamsteed: the nebula M 8 in Sagittarius and an asterism near 43 Sgr.[27] Finally, there is the open cluster M 50 in Monoceros, discovered by Giovanni Domenico Cassini.[28]

Thanks to these seminal books, Herschel became aware of remarkable stars, star clusters and nebulae. Alas, no positions were given. To locate these objects, a star catalogue and a celestial map were needed. Again, Ferguson pointed the way: "The *British* catalogue, which besides the Stars visible to the bare eye, includes a great number which cannot be seen without the assistance of a telescope, contains more than 3000, in both Hemispheres."[29] He further recommended "*Senex's* globes, *Bayer's* letters are inserted".[30]

The *British Catalogue* was John Flamsteed's main work. About the year 1700, he had measured accurate positions of stars with a mural circle at the Royal Observatory, Greenwich; 2936 were included in the catalogue with coordinates (AR and PD in degrees) for the equinox 1690. The first Astronomer Royal died in 1721, and the work was not published until 1725 as *Stellarum inerrantium Catalogus Britannicus ad annum Christi completum 1689*. Actually, the catalogue is contained in the third of three volumes of the *Historia Coelestis Britannica*; the corresponding *Atlas Coelestis* didn't appeared until 1729.[31]

Shortly after Flamsteed's death, John Senex[32] published two maps of 25.7″ × 25.2″ of the northern and southern hemisphere: *Stellarum Fixarum Hemisphaerum Boreale* and *Stellarum Fixarum Hemisphaerum Australe* (Figure 1-5), containing all stars of the *British Catalogue*. The maps satisfied a great demand in England for single-sheet, reliable star charts, and the black-on-white printings became popular for both astronomers and navigators.

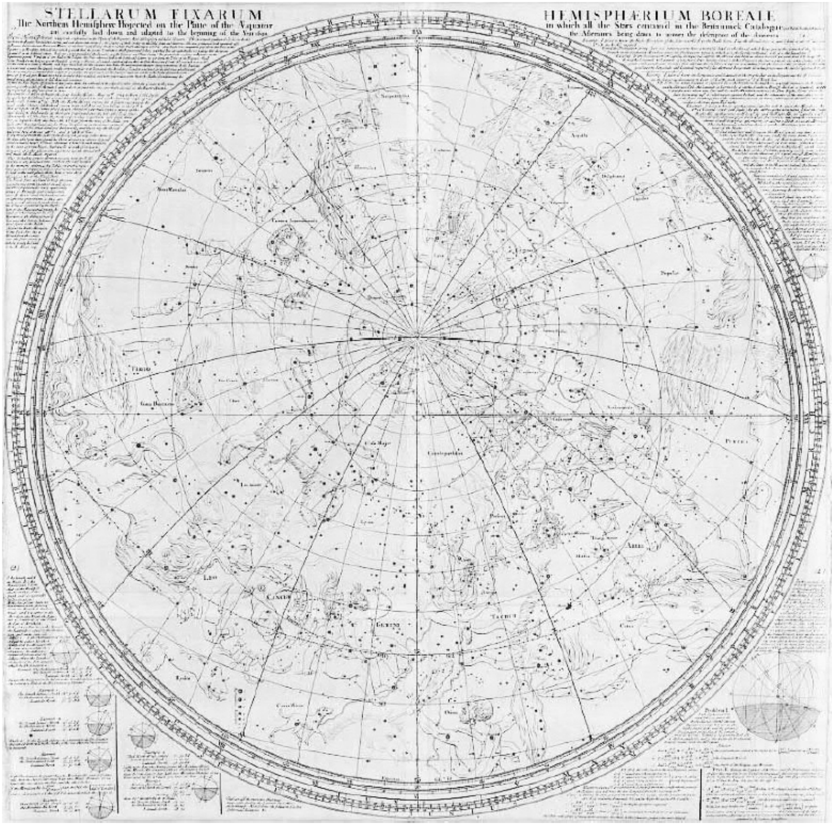


Figure 1-5: The northern star map of 1721, conceived by Edmond Halley and engraved by John Senex (diameter 35 inches).

The driving force behind the project was Edmond Halley, the new Astronomer Royal. He had access to Flamsteed's northern sky data. The southern extension (below -30°) is based on his own observations. The northern map, engraved by Senex, appeared in 1721. However, another engraver is mentioned for the southern map, published in 1728, the Welsh astronomer Joseph Harris.[33]

About 1200 stars are labelled on the maps (down to about -30° declination). The designations are based on the *Uranometria*, the famous star atlas, published by Johann Bayer in 1603.[34] The brighter stars bear lower case Greek letters (sorted by magnitude); some have names, like Rigel (β Ori). The German astronomer also introduced Latin upper/lower case letters for fainter stars (e.g. in

Gemini: A, b, c, d, E, F, G, H, I, K). Bayer's nomenclature was used by Flamsteed.[35] The naked-eye clusters of the Hyades, Pleiades (M 45) and Praesepe (M 44) are so named; six non-stellar objects are marked on the maps as 'Nebula': M 11 (open cluster in Scutum), M 13 (globular cluster in Hercules), M 22 (globular cluster in Sagittarius), M 31 (Andromeda Nebula), M 42 (Orion Nebula) and ω Centauri (globular cluster); see Figure 1-6.

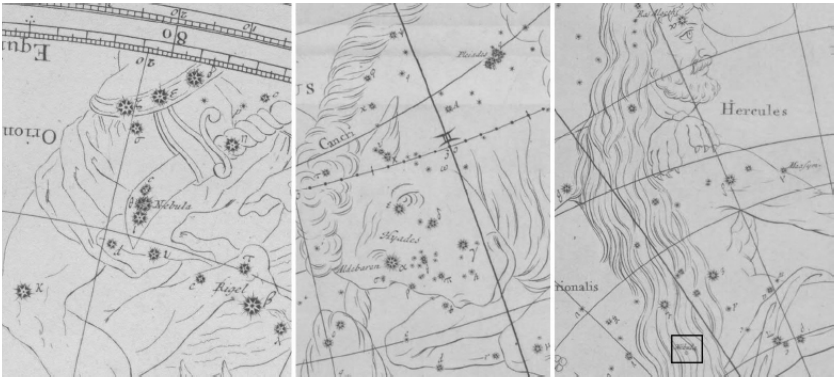


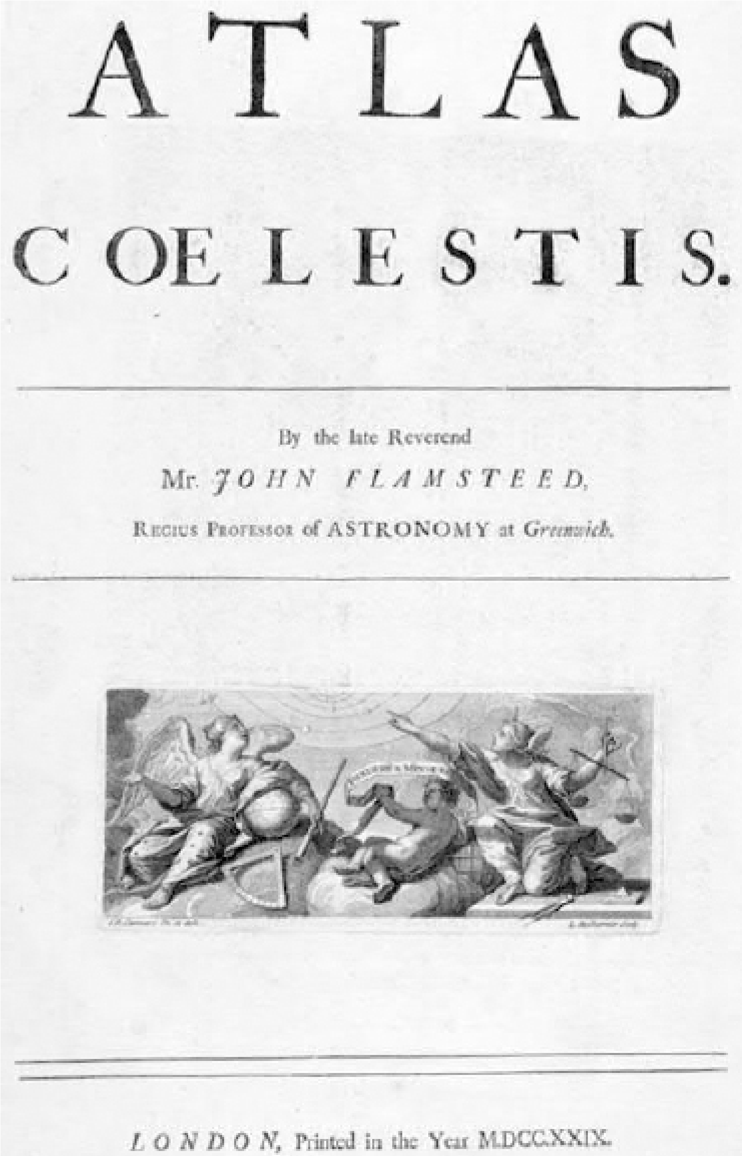
Figure 1-6: Non-stellar objects on the Harris maps. Left: the Orion Nebula (southern map); centre: the large open clusters of the Hyades and Pleiades in Taurus; right: the globular cluster M 13 in Hercules, discovered by Halley in 1714, shown as 'Nebula' (in the frame).

In Herschel's *Memorandum* we read for August 1774:[36] "Maps. Glasses. Putty. & Astronomical timepiece." This refers to the *British Catalogue* and the 'Harris's maps', so called by him. However, this is not fully correct, because the Welsh astronomer was responsible only for the southern edition.[37] Unfortunately, we do not have Herschel's copy.

Table 1-1 lists 13 true deep-sky objects, known to William Herschel from the inspiring books of Smith and Ferguson, when he started his observations in 1774.[38] Nine are plotted on the Harris maps (the case of the Double Cluster is special, see Figure 1-36). The others (M 7, M 8 and M 50) had to wait until Herschel had the *Messier Catalogue* in his hands. Actually, he 'discovered' M 8 in his second star review (see section 1.8).

Source	Reference	Object	Con	Type	Harris map
Smith	Halley	M 42 (Orion Nebula)	Orion	nebula	south
Smith	Halley	M 31 (Andromeda Nebula)	Andromeda	galaxy	north
Smith	Halley	M 22	Sagittarius	globular cluster	south
Smith	Halley	ω Centauri	Centaurus	globular cluster	south
Smith	Halley	M 11	Scutum	open cluster	south
Smith	Halley	M 13	Hercules	globular cluster	north
Ferguson	-	Hyades	Taurus	open Cluster	north
Ferguson	-	Pleiades	Taurus	open Cluster	north
Ferguson	Ptolemy	Double Cluster	Perseus	open cluster	(north)
Ferguson	Ptolemy	M 44 (Praesepe)	Cancer	open cluster	north
Ferguson	Ptolemy	M 7	Scorpius	open cluster	-
Ferguson	Flamsteed	M 8	Sagittarius	nebula	-
Ferguson	Cassini	M 50	Monoceros	open cluster	-

Table 1-1: Nebulae and star clusters, known to Herschel from the books of Smith and Ferguson or the Harris maps. The positions of M 7, M 8 and M 50 were unknown to him. Flamsteed's *Atlas Coelestis* shows no non-stellar objects. Of course, ω Centauri was too far south for him to see.



ATLAS

COELESTIS.

By the late Reverend

Mr. *JOHN FLAMSTEED*,

Regius Professor of ASTRONOMY at *Greenwich*.

LONDON, Printed in the Year MDCCXXIX.

Figure 1-7: Title page of John Flamsteed's *Atlas Coelestis*, published in 1729.

In 1781 another item was added to Herschel's library: Flamsteed's *Atlas Coelestis*, not in the original edition of 1729 (Figure 1-7) but in a new one. The bulky item, measuring 24″ × 19″, had just been

published by C. Nourse of The Strand, London.[39] The stellar database is the *British Catalogue*. The northern sky down to -30° declination is presented on 29 charts printed on double pages, each featuring a certain constellation. Unlike the Harris maps, the *Atlas Coelestis* shows no nebulae or clusters.[40] For some time, Herschel used both Harris maps and Flamsteed's atlas for his observations.

1.2.2. Herschel's early document series

The first series of observing notes, called *Journal*, was started on 1 May 1774. It mainly concerns objects of the Solar System. Herschel's first observations are listed in Table 1-2. Figure 1-8 shows early drawings.

Object	First observation	Telescope
Saturn	1 March 1774	5.5-ft
Jupiter	15 December 1774	5.5-ft
Moon	28 May 1776	10-ft
Mars	8 April 1777	small 20-ft
Venus	17 April 1777	10-ft
Sun	19 April 1779	7-ft

Table 1-2: Herschel's first telescopic observations of Solar System objects; Mercury was first seen on 14 November 1783, though with the naked eye (see *Journal No. 1*).

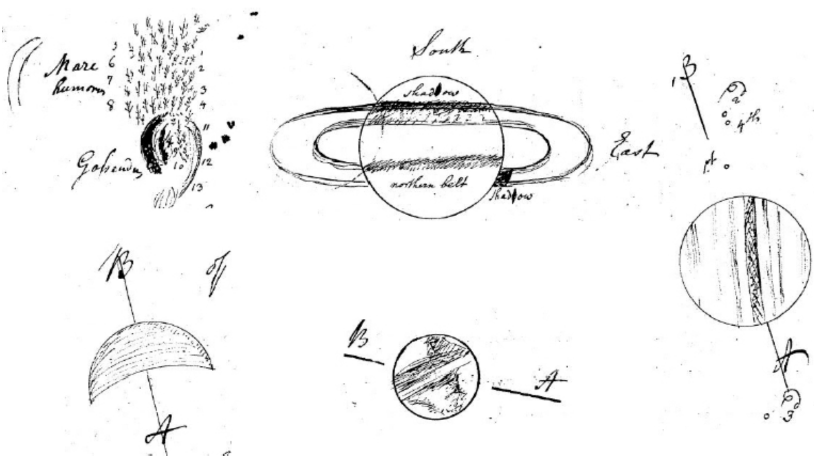


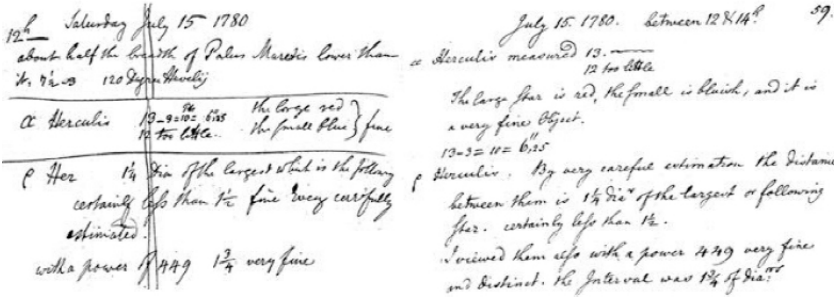
Figure 1-8: Early drawings: Moon with 'trees' (28 May 1776),

Saturn (13 July 1776), Venus, Jupiter (both 17 April 1777), Mars (27 April 1777). For the Moon the 7-ft was used, for planets the 'small 20-ft'. The A-B-line means east-west (sky motion).

The first Moon observation was surprising, to say the least: "In the moment I saw the Moon I was struck with the appearance of something I had never taken notice before and which I immediately too to be woods or large quantities of growing substance in the Moon." Herschel's 'wood' is located south of Gassendi crater in Mare Humorum.

Concerning the Sun, we must ask, how could Herschel safely observe it with his instruments? On 19 April 1779, his first telescopic view of the Sun, he wrote: "There was a spot on the sun which was large enough to be seen with the naked eye. By a view of it with a 7-feet reflector, charged with a very high power, it appeared to be divided into two parts."[41] Much later, on 8 September 1792, we read: "Having made a small speculum, merely brought to a perfect figure upon hones, without polish, I found, that by stifling a great part of the solar rays, my object speculum would bear a greater aperture; and thus enabled me to see with more comfort, and less danger." And on 23 February 1794: "By an experiment I have just now tried, I find it confirmed that the sun cannot be so distinctly viewed with a small aperture and faint darkening glasses, as with a large aperture and stronger ones; this latter is the method I always use."[42]

In the first entries, some deep-sky objects appear in *Journal No. 1*, but on 7 March 1775 they got their own series, the *Fixt Stars*. The occasion was Herschel's observing campaign, called 'star review'. Both series were written by William.[43] The observations are entered by date. *Journal* records concerning objects, not belonging to the Solar System were transferred to the *Fixt Stars*, where the information often appears more detailed. Copied pages are marked in the *Journal* by a vertical double line (Figure 1-9).


12h Saturday July 15 1780
about half the breadth of Palus Maeotis lower than
α Herculis 13–9=10= 6,25 / 12 too little — the large red / the small blue } fine
ρ Her 1¼ dia of the largest which is the following certainly less than 1½ fine very carefully estimated!
with a power of 449 1¾ very fine

July 15. 1780. between 12 & 14h 59.
α Herculis measured 13. / 12 too little
The large star is red, the small is bluish, and it is a very fine Object.
13–3= 10 = 6,25
ρ Herculis. By very careful estimation the distance between them is 1¼ dia. of the largest or following star. certainly less than 1½.
I viewed them also with a power 449 very fine and distinct. the Interval was 1¾ of dia.

Figure 1-9: A vertical double line indicate the transfer of entries (concerning deep-sky objects) from *Journal No. 2* to *Fixt Stars No. 1*. However, the first entry (concerning the Moon) was not copied.

A third document series, named *Review*, was started on 17 August 1779. The first four volumes contain only tabular listings of stars.[44] The *Review* series was exclusively managed by Caroline (for the authorship compare 2.1.4). Table 1-3 lists the documents, relevant for Herschel's three 'star reviews' (see next sections).

Document	Author	Period	RAS	Content
Journal No. 1	W	1 Mar. 1774 – 26 Sep. 1779	W.2/1.1	1st & 2nd review
Journal No. 2	W	15 Jul. 1780 – 14 May 1781	W.2/1.2	2nd review
Journal No. 3	W	20 May 1781 – 20 Jan. 1782	W.2/1.3	2nd & 3rd review
Journal No. 4	W	6 Feb. 1782 – 6 Nov. 1782	W.2/1.4	3rd review
Journal No. 5	W	6 Nov. 1782 – 2 Apr. 1783	W.2/1.5	3rd review
Journal No. 6	W	2 Apr. 1783 – 24 Sep. 1783	W.2/1.6	3rd review
Journal No. 7	W	25 Sep. 1783 – 19 Feb. 1784	W.2/1.7	3rd review, sweep 1–150
Fixt Stars Vol. 1	W	7 Mar. 1775 – 24 May 1781	W.4/1.1	1st – 3rd review
Fixt Stars Vol. 2	W	26 May 1781 – 5 Apr. 1782	W.4/1.2	2nd & 3rd review
Fixt Stars Vol. 3	W	5 Apr. 1782 – 31 Dec. 1782	W.4/1.3	3rd review; p. 264 & 265 missing
Fixt Stars Vol. 4	W	31 Dec. 1782 – 30 Jun. 1783	W.4/1.4	3rd review
Fixt Stars Vol. 5	W	30 Jun. 1783 – 17 Jan. 1784	W.4/1.5	3rd review, sweep 1–79
Review No. 1	C	17 Aug. 1779 – 6 Aug. 1780	W.2/2.1	2nd review
Review No. 2	C	19 Ag. 1780 – Aug. 1781	W.2/2.2	2nd review
Review No. 3	C	Aug. 1781 – Nov. 1781	W.2/2.3	2nd & 3rd review
Review No. 4	C	1 Jan. 1782 – 23 Dec. 1783	W.2/2.4	3rd review

Table 1-3: The documents, written 1774–84, contain data of the 'star reviews' and early sweeps (for later documents, see Table 2-5). The originals are stored in the Herschel Archive of the *Royal Astronomical Society* (RAS), London.

1.2.3. The mysterious first 'star review' and larger reflectors

Until the end of April 1776, the focus of Herschel's observations with the 5½-ft reflector was on Saturn and its five known satellites. There are 19 entries in the *Journal*. On 1 May 1776, a larger telescope was used for the first time: "Observed Saturn with a new Reflector. Focus 7 ft."[45] The new instrument may have motivated him to inspect the brighter stars. Inspired by his surprising view of Mizar, his goal was the detection of other double stars. However only a few stars appear in other records from that time. Until about spring 1777, Herschel was still much concerned with music. Caroline then wrote that "public business ended, and my brother had now a little more time for perfecting his instruments and looking at the heavens in fine nights".[46] There is no doubt that William intended to advance astronomy, both instrumental and theoretical. To get the observational basis for the latter, a systematic sky review was needed.

In a paper of 1783, we read:[47] "The first [review] was made with a Newtonian telescope, something less than 7 feet focal length, a power of 222, and an aperture of 4½ inches. It extended only to the stars of the first, second, third, and fourth magnitudes." The Harris maps were the source. The first review, started in early 1778, would need at least six months, since stars with low declination (Sirius, Antares) appear only for a limited period.

Nothing is recorded about a 'first review' in the *Journal*; the *Fixt Stars* series gives a hint. The first pages show a collection of stars, looking strange.[48] There are cryptic rows like "Capella. Regulus 70. Syrius [Sirius] 66. Elgeuse [Betelgeuse] 40¼. Aldebaran 31, Rigel 54½. Procyon 51½. Castor 30. Pollux 34½." or "Arcturus. Lyra [Vega] 59. Spica 33¼. Regulus 60. Antares 56½." Herschel used the Harris maps and noted the angular distance in degrees between the primary star (Capella or Arcturus) and the following ones (Regulus or 'Lyra', respectively). This might have directed Herschel's observations. On 8 April 1778, a first success was noted: "The distance of the two stars in the head of Castor seems to be something less than the apparent diameter of the smallest of them; which is the southernmost. This observation was taken with the 7-ft Reflector power 146." This marks Herschel's detection that Castor (β Gem) is a double star[49] – the third example after θ Ori and ζ UMa (Mizar); Table 1-4 shows all double stars, found prior to

Herschel.

Double/multiple star	Discoverer	WH	Remark
Mizar (ζ Ursae Majoris)	Castelli 1617	1774	Riccioli ca. 1650
θ Orionis	Huygens 1656	1774	Trapezium in Orion Nebula
Castor (α Geminorum)	G. D. Cassini 1678	1778	Cassini saw the main pair of the sextuple system
Ras Algethi (α Herculis)	Maskelyne 1777	1779	
γ Arietis	Hooke 1664	1779	
ν Draconis	Flamsteed 1690	1779	optical double
Albireo (β Cygni)	Flamsteed 1691	1779	large colour contrast
γ Virginis	Bradley 1718	1780	
61 Cygni	Bradley 1753	1780	Bessel's parallax star of 1838

Table 1-4: Double stars, found prior to Herschel (WH).50 In early 1778, he knew only the first three; Ferguson's *Astronomy* and the *British Catalogue* tell nothing about the matter. WH = year of Herschel's independent discovery.

Herschel's theoretical goal is apparent from an observation, made on 28 January:51 "I examined Syrius but found no small star near enough for the purpose of parallax." The same resulted for Procyon on 7 February. What is the connection between parallax and double stars? It is due to Galileo Galilei.52 The Italian astronomer had the idea that an optical pair of stars might provide a perfect distance indicator. If two stars are close together on the sphere but at different distances in space, the farther star would in effect be a fixed point against which we could measure the apparent movement of the nearer star. Due to the orbital motion of the Earth, the nearer star should appear to move away from the 'fixed' star when the Earth moves to the extremes of its orbit. By measuring the angles and knowing the orbit's radius (astronomical unit), we could determine the distance to that star. Of course, this method would not work if the stars were orbiting each other and were therefore at the same distance from us.

Herschel probably heard about Galileo's idea from Nevil Maskelyne, who visited Bath in 1777.53 In January 1778, he treated the parallax method in his *Journal No. 1*.54 The theoretical basis of the approach was not published until 1782, when his paper 'On the Parallax of the Fixt stars' appeared in the *Philosophical Transactions*.55 As Maskelyne, wrote in a letter to Herschel on 19 April, the paper was "highly applauded for its ingenuity and the new light it throws on that difficult subject".56 However, a certain point in Herschel's treatment was criticized: "I should also mention

that the principle that all the fixt stars are equal in real magnitude and lustre to one another and to our Sun, seems a very hard hypothesis and not agreeable to the very great variety observable in the works of nature." Herschel saw himself misunderstood, replying: "When I say 'Let the stars be supposed *one with another* to be *about* the size of the Sun', I only mean this in the same extensive signification in which we affirm that *one with another* Men are of such or such a particular height. This does not exclude the Dwarf, nor the Giant." The Astronomer Royal also mentioned the important paper on the subject published in 1767 by John Mitchell.[57] The author stated that, by statistical arguments, it is probable that true double stars exist, orbiting each other, especially in the case of a significant brightness difference. Herschel maintained that it was "too soon to form any theories of small revolving round large ones".

Except Castor, Herschel's first review brought no result. Perhaps the necessary engagement was lacking, for his main interest was still focused on Moon and planets. From 1 March 1774 to 18 July 1779, he observed in 96 nights; 83 of them were more or less dedicated to the Solar System. Of course, a serious campaign with the 7-ft would have found many double stars. This would change dramatically in the second review.

Meanwhile the construction of reflectors was making progress, tending to larger apertures and greater focal lengths. Herschel had already used a 10-ft (aperture 9 inches) on 28 May 1776 to observe the Moon. On 13 July, he viewed Saturn with a 20-ft reflector of 12 inches aperture, known as the 'small 20-ft' (Figure 1-10).[58] With its long focal ratio of 1:20 it needed a special stand, similar to that used for the incredible air refractors of the seventeenth century.[59] Herschel wrote:[60] "With my 20feet telescope I use a long pole to the top of which is fastened a very short arm holding a set of pulleys, and when the telescope is elevated by them I use a moveable ladder with a back to mount up to the eye piece." Though the tube was fixed to the meridian[61], there were fine vertical and lateral motions; the latter was controlled by a mechanism at the tube base. The long instrument required the observer to stand precariously on an adjacent ladder; not an easy task, especially in windy conditions.

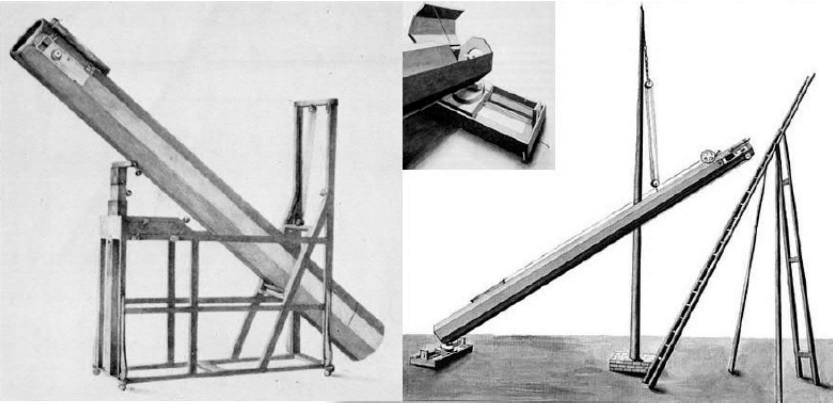


Figure 1-10: Left: Herschel's 10-ft reflector with an aperture of 9 inches, constructed in early 1776. Right: the 'small 20-ft' reflector with an aperture of 12 inches, erected in July 1776, with a simple mast and pulley mounting plus ladder. The inset shows the mechanism at the bottom (screw) to allow a horizontal motion of the tube, used for object tracking; it was controlled by the observer. The drawings were made by William Watson Jr in July 1778.[62]

On 11 November 1776 at 10 pm, the 10-ft reflector was pointed at the 'Lucid Spot in Orion' (M 42). With magnification 120, Herschel now detected a fourth star in the centre of the nebula.[63] He made a sketch (Figure 1-11), noting: "The figure is only drawn for the description." The name Trapezium for the striking θ Ori quartet is due to Herschel, writing in the first catalogue of double stars for the entry III 1:[64] "Quadruple. It is the small telescopic Trapezium in the Nebula." The Orion Nebula was sketched again on 25 January 1778 (Figure 1-11). Further observations appeared on 7 and 25 February and 15 December 1778, although no changes of the nebulous mass were detected.[65]

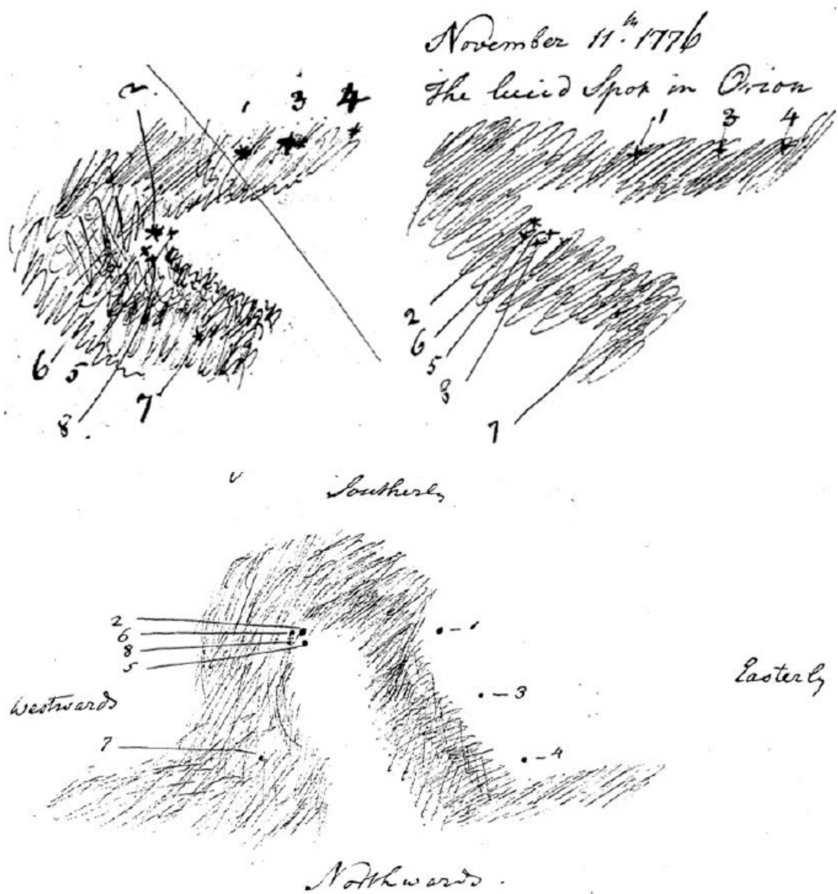


Figure 1-11: Above: Herschel's second sketch of the Orion Nebula, made on 11 November 1776. It shows star quartet of the Trapezium (θ Ori). The *Journal* version (left) was copied to *Fixt Stars No. 1* (right). Below: The third sketch, made on 25 January 1778; both were made with the 10-ft.

1.3. The second star review: the 7-foot reflector at work

1.3.1. The number of double stars grows

17 August 1779 was a notable date. It marks Herschel's turn to stellar astronomy: the second star review (the first serious one) was

started. For the ambitious observing campaign, he created a new document series. It was called *Review* and managed by Caroline (see section 1.2.2). *Review No. 1* gives the sub-title 'Second Review'.[66] The terminology is confusing, but reflects the fact that William had not made much of his 'first review'. The introduction starts with the remark: "The stars are taken from Harris's Sheet Hemispheres". The new series is essentially a list of all observed stars with their Bayer letter, made for bookkeeping (*Review No. 2* shows the constellations in alphabetic order). The Harris maps, of course, include some historic constellations, like Antinous, Cerberus and Ramus, Triangulum minor, Mons Menelaos and Argo Navis, which have now been integrated into other ones. In addition, some names have changed (e.g. Serpentarius to Ophiuchus). Curiously, Herschel created 'Effusion', flowing out of the jar, held by Aquarius, right into the mouth (Fomalhaut) of Piscis Austrinus.[67] Usually, a constellation, double star (e.g. Castor) or remarkable star (e.g. Mira) was observed several times. The results were entered in the *Journal* or *Fixt Stars*.

The night of the 17th brought three new double stars, which increased Herschel's number to six. He observed with his 7-ft with 4-inch mirror at 222×, as used in the first review. The search was made in the north:[68] "In order to attempt this solution of parallax it will be necessary again to examine the circumpolar stars if any can be found to answer the intention." Starting at Capella, he proceeded to Draco and Ursa Major. The brightest stars all appeared single, except Mizar ("this is the well-known double star"). Perseus, Cassiopeia and Cepheus came next. Here Herschel found what he was looking for: η and ι Cas were found to be double. For the Pleiades he noted: "all the principle stars are single tho' Cassini observes that they sometimes [underlined] appear otherwise."[69]

Finally, Ursa Minor was visited – yielding a spectacular result: "I believe there is an exceedingly small star near the pole star, the night is not fine enough to determine." Herschel tried again on the 21st, using the same instrument: "The Pole Star is double but one of them is exceedingly small that I even sometimes doubted whether it was there at all or not." Herschel added: "I shall try a telescope with more aperture on it." This was done on the 22nd with a new Newtonian reflector of 6.2 inches aperture. It had an octagonal

cocus wood tube on a mahogany stand and was operational in November 1778.70 The result was clear: "I applied 6 inches of aperture to the Pole Star, power 313, and it showed the small star directly much plainer than the 7ft with 4 inches aperture used to do. I showed it to my sister who without knowing where it was told me the place where she saw it, which agreed with my observation."

Though this unique object, Polaris, had been observed by many astronomers, none had ever noticed its duplicity.71 Joseph Banks and Nevil Maskelyne congratulated Herschel.72 The discovery was a demonstration of the superiority of his telescope – also proven by the fact that it could not be confirmed until March 1782. Herschel's friend Alexander Aubert saw the 9th mag companion in a Dolland refractor of 3.5 feet focal length at magnification 1000.73 Table 1-5 lists Herschel's first six double stars.

Star	Date	Reflector	Remarks
θ Ori	9 Apr. 1774	5½-ft (4.5-in)	Huygens 1656 & 1684. Herschel saw three stars of the Trapezium; the 4th followed on 11 Nov. 1776
Mizar (ζ UMa)	9 Apr. 1774	5½-ft (4.5-in)	Castelli 1617
Castor (α Gem)	8 Apr. 1778	7-ft (4-in)	G. D. Cassini 1678
η Cas	17 Aug. 1779	7-ft (4-in)	
ι Cas	17 Aug. 1779	7-ft (4-in)	
Polaris (α UMi)	17 Aug. 1779	7-ft (4-in)	Pole star, seen again 22 Aug. with 7-ft (6.2-in), confirmed by Aubert 1782

Table 1-5: Herschel's first double/multiple stars.

The new 7-ft reflector is mentioned in Herschel's *Memorandum* for 17 August 1779: "I began a regular review of the heavens with a very good 7ft reflector."74 This statement is not quite correct, because in that night and the following until the end of August, the old 7-ft reflector (4-inch mirror) was still used in the second review. The actual change to the larger instrument can be derived from the detection of the famous 'double double' ε Lyr on 29 August and the very close double star ε Boo on 9 September (which was seen 'single' on 25 August).

In 1783, Herschel gave more details on the new reflector:75 "My second review […] was made with an instrument much superior to the former, of 85.2 inches focus, 6.2 inches aperture, and power 227. It extended to all the stars in HARRIS'S maps, and the telescopic ones near them, as far as the eighth magnitude." Note

that this instrument is different from a previously-mentioned 7-foot, first used in May 1776, having only 4 inches aperture. The new 7-ft reflector, with a large focal ratio of 13.7, became operational in November 1778. This may also mark the end of the 'first review'. The long octagonal tube was held by an ingenious azimuthal mounting. Any celestial position could be reached in a minute.[76] Due to fine vertical and lateral motions, accessible to the observer at the eye-piece, object tracking was an easy task. Results were immediately recorded at the telescope, using candlelight. (For stars the loss of dark adaptation was not a serious problem.)

The 7-ft with its mirror of 6.2 inches diameter became Herschel's standard reflector for many years – it brought the epochal discovery of a new planet (Uranus) in March 1781. In 1780, he wrote:[77] "I believe, that for distinctness of vision this instrument is perhaps equal to any that was ever made." However, in January 1781, he thought about an instrumental quantum leap: a 30-ft reflector with a mirror of 3 feet diameter and a pole mounting like the 'small 20-ft'; though a mirror was cast on 11 August. It later cracked and the instrument was never completed (see Figure 2-109).[78]

A few days later, on 29 August 1779, Herschel found 11 double stars in a single night. Among them were prominent exemplars like Ras Algethi (α Her)[79], β Lyr and ε Lyr, the famous 'double-double'. A few other interesting double stars, found later in the second review, should also be mentioned: Albireo (β Cyg) on 12 September 1779 and described as "two fine stars one red the other blue", Cor Caroli (α CVn) on 7 August 1780, 61 Cyg (Bessel's celebrated parallax star of 1838) on 20 September 1780 and Alnitak (ζ Ori), the left star in Orion's belt, on 10 October 1780.

On 19 October 1779, Mira was seen 'double' in the 7-ft.[80] The companion is 2' east of the variable star and has a brightness of 9.4 mag. The pair is only optical. A similar judgement applies to Rigel (β Ori). On 1 October 1781, the 0.3 mag star was seen 'double' in the 7-ft at 227×. The distance of the 6.7 mag companion, located southeast, was later measured as 10". On 2 April 1783, when using the small 20-ft, Herschel made a sketch (Figure 1-12).[81]

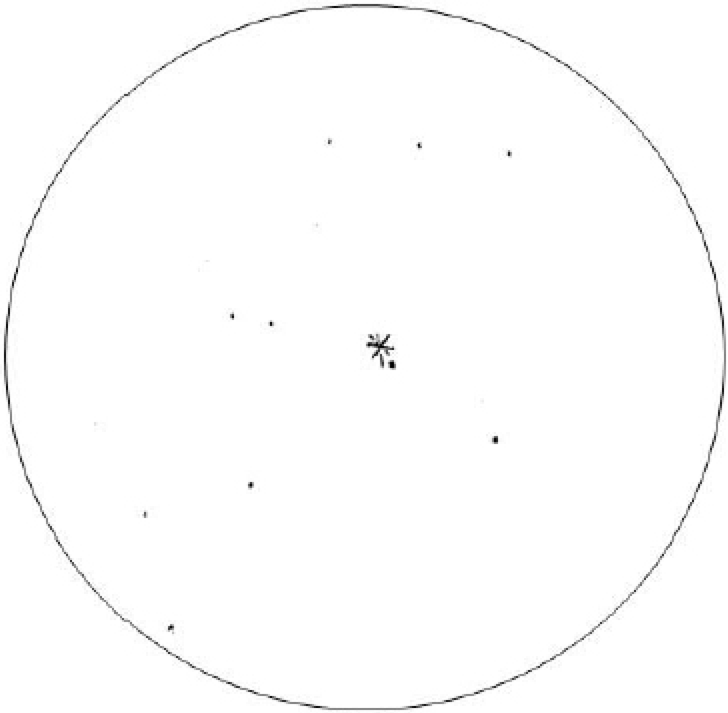


Figure 1-12: Herschel's sketch of the optical double star Rigel, made at the small 20-ft on 2 April 1783. The field of view is about 20'.

Herschel's second review lasted 26 months, from 17 August 1779 to 20 October 1781. Most of the time the standard magnification (227) was used, but on 21 July 1781 he turned to 460 × (the eye-piece of the third review).[82] Of the 225 observing nights, 183 were dedicated to stars (occasionally planets were observed). An impressive number of 251 double stars was found, 151 of them are stars, plotted on the Harris maps; the rest were found in the vicinity of mapped stars. Herschel's double stars will be discussed in more detail later, in connecting with his three published catalogues. Table 1-6 presents statistical data for the second review.

Subject	Location / number	Date
most northern CON	Ursa Minor	
most northern DS	Polaris (α UMi) at $\delta = +89^\circ$	17 Aug. 1779
most southern CON	Musca, Piscis	

	Austrinus, Puppis (‘Argo’)	
most southern DS	Markeb (κ Pup) at $\delta = -27°$	15 Feb. 1781
most visited CON	Boötes (67), Lyra (45), Cetus (36)	
last visited CON	Puppis (1), Coma Berenices, Canis Minor, Corvus, Musca (all 2)	
max. number of CON/night	13	27 Sep. 1779
max. number of DS/night	11	29 Aug. 1779

Table 1-6: Statistics for the second review (CON = constellation, DS = double star). The large numbers for Boötes, Lyra and Cetus are due to often-visited stars like ε and ξ Boo, ε Lyr and Mira (ο Cet).

During the second review, Herschel had two guests observing with his telescopes. On 28 August 1780, William Watson viewed Jupiter in the small 20-ft and on 8 September he even measured some features on the Moon. On the 28th, the 7-ft got new primary and secondary mirrors (“both very excellent”).[83] On 20 July 1781, Patrick Brydone observed the double star α Her with the 7-ft; he noticed that “one of them was red the other greenish”.[84]

Besides the 251 new double stars, the second review brought three new star clusters (see section 1.8). But that was nothing compared to Herschel’s greatest discovery made in the campaign: Uranus.

1.3.2. The coincidental but inevitable discovery of Uranus

Occasionally Herschel encountered a brighter star, not plotted on the Harris maps. This first happened on 18 August 1780, when he saw in his 7-ft “a star not marked in my map tho’ visible to the naked eye full as well as μ Draconis […] thus it is surprising that it should have been overlooked in the Catalogue or map”. Obviously, he had also consulted Flamsteed’s *British Catalogue*. Herschel had

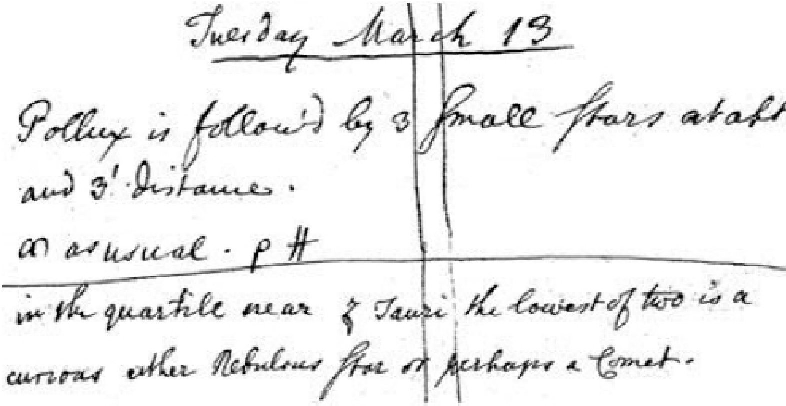
detected on 19 October 1779 that μ Dra is a double star. The unmapped star was located 3.5° northwest of it, shining even more brightly.[85]

The following year, Herschel found another uncatalogued stellar object, located 3.5° west of the Bayer star H Geminorum, which was plotted on the northern Harris map within the boundary of Taurus.[86] This would turn out to be Uranus, discovered on Tuesday, 13 March 1781.[87]

Figure 1-13: Left: Current view of the garden at 19 New King Street, Bath, the site of the Uranus discovery (the trees must have been lower at that time). Right: This pretty picture of William and Caroline, found in the literature, is meant to show how the siblings discovered the planet. It is, of course, ridiculous! Caroline did not assist her brother in March 1781 and such a round-tube equatorial Newtonian (looking fairly modern) was never used.

In the previous night, Herschel had started an examination of Gemini to inspect some brighter stars of the constellation and their vicinity.[88] In the night of the 13th, Castor was seen in the 7-ft reflector at 227× "as usual". Then he observed the rest of Gemini, finding four double stars. At 10:30 pm, he turned his telescope westwards to a 'quartile' (rectangular area) at the Gemini/Taurus border. The area was 33° above the western horizon. The 7-ft was erected in the backyard garden of his house at 19 New King Street (Figure 1-13), which the siblings had just moved into. Because the building was to the north, Herschel had a good view towards all other directions.

There are three reports about the discovery, differing in their amount of information: (1) appears in *Journal No. 2* (Figure 1-14);[89] (2) is in *Fixt Stars No. 1* (here Herschel is more detailed, now mentioning the time);[90] (3) is from his paper 'Account of a Comet', read to the *Royal Society* on 26 April and published in the *Philosophical Transactions* (Figure 1-15).[91]



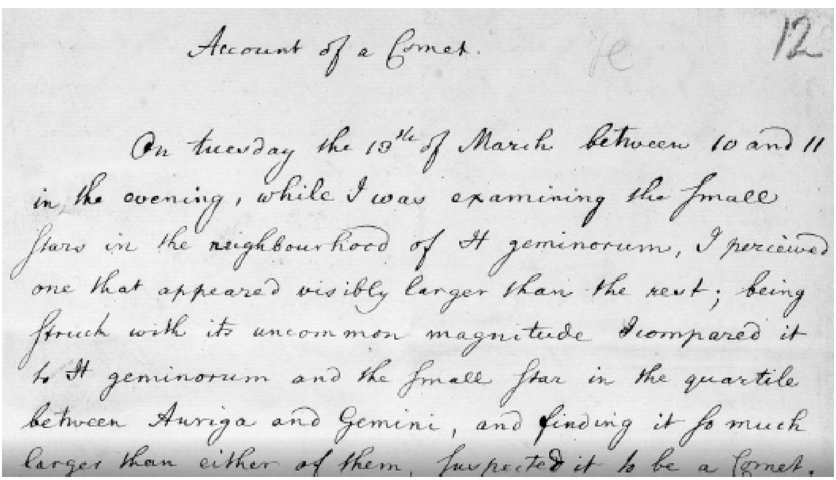
Tuesday March 13

Pollux is follow'd by 3 small stars at abt 2' and 3' distance.

∞ as usual. p H

in the quartile near ζ Tauri the lowest of two is a curious either Nebulous star or perhaps a Comet.

Figure 1-14: Herschel's entry of the Uranus discovery in *Journal No. 2*, dated 13 March 1781.



Account of a Comet. 12

On tuesday the 13th of March between 10 and 11 in the evening, while I was examining the small stars in the neighbourhood of H geminorum, I perceived one that appeared visibly larger than the rest; being struck with its uncommon magnitude I compared it to H geminorum and the small star in the quartile between Auriga and Gemini, and finding it so much larger than either of them, suspected it to be a Comet.

Figure 1-15: Caroline's manuscript of his brother's paper on the Uranus discovery.

The essential parts concerning the Uranus discovery, as given in the

three documents (Figure 1-16):

(1) In the quartile near ζ Tauri the lowest of two is a curious either nebulous star or perhaps a Comet [...] a small star follows the comet at ⅔ of the field distance.

(2) About 10^h 30' near the 4/ [4^{th} corner] in the quartile nearest to ζ Tauri is a curious nebulous star. Perhaps it is a comet. The appearance of this star was so different from the rest that I examined it a good deal and compared it with other stars to see if my telescope was faulty, but found it in good order. 11^h 30' suspecting the star to be a comet I took a superficial measure merely by comparing it to my field of view and found that it was followed by a small star at the distance of ⅔ of the field; and that the small star seemed to follow directly.

(3)On Tuesday the 13th of March, between ten and eleven in the evening, while I was examining the small stars in the neighbourhood of H Geminorum, I perceived one that appeared visibly larger than the rest: being struck with its uncommon magnitude, I compared it to H Geminorum and the smaller star in the quartile between Auriga and Gemini, and finding it so much larger than either of them, suspected it to be a comet.

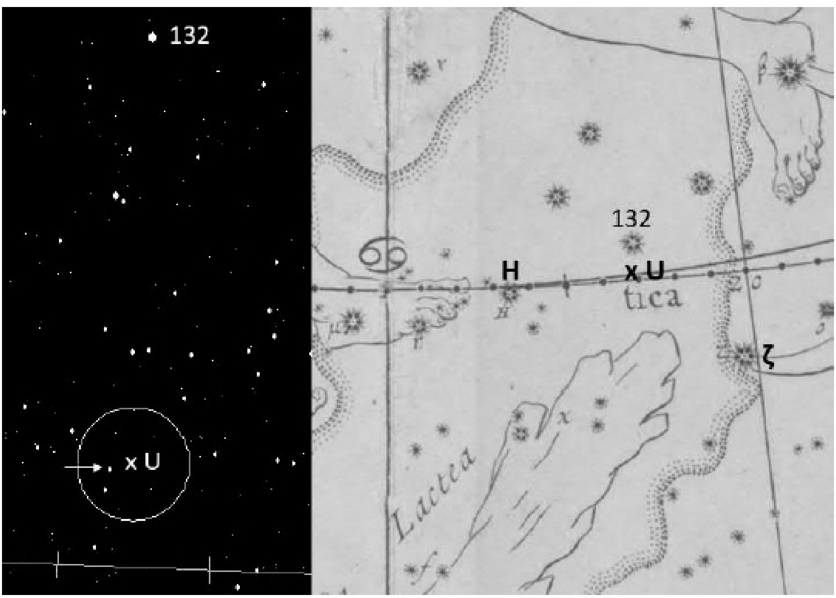


Figure 1-16: The discovery situation on the Harris map around H Geminorum. In (1), the star meant in "the lowest of two" is 132 Tau (4.9 mag); in (2) the "small star at the distance of ⅔ of the field" is SAO 77598 (9.2 mag); marked by an arrow on the inset.

Shortly after the discovery, Herschel informed the Astronomer Royal, Nevil Maskelyne, and Thomas Hornsby, Director of Radcliffe Observatory at Oxford.[92] On 4 April, Maskelyne wrote a letter to William Watson about his own observation: "The last three nights I observed stars near the position pointed out by Mr Herschell [sic], whereby I was enabled last night to discern a motion in one of them [this] convinces me it is a comet or a new planet, but very different from any comet I ever read any description of or saw. This seems a comet of a new species, very like a fixed star." And on the 23rd Maskelyne wrote to Herschel:[93] "On the 6th of April I viewed the comet with my 6 ft. reflecting telescope and greatest power 270, and saw it of a very sensible size but not well-defined. This however showed it to be a planet and not a fixt star."

Re-examining the unusual object on 17 April, Herschel had independently found that there was a motion towards the east. His published paper contains observations of the 'comet' until the 19th. There, he describes the appearance of the object under higher powers:

I had already at hand the several magnifiers of 227, 460, 932, 1536, 2010, &c., all of which I successfully used upon that occasion. The power I had on when I first saw the comet was 227. From experience I know that the diameters of the fixed stars are not proportionally magnified with higher powers, as planets are; therefore I now put the powers at 460 and 932, and found that the diameter of the comet increased in proportion to the power, as it ought to be, on the supposition of its not being a fixed star, while the diameters of the stars to which I compared it were not increasedin the same ratio. Moreover, the comet being magnified much beyond what its light would admit of, appeared hazy and ill-defined with these great powers, while the stars preserved that lustre and distinctness which from many thousand observations I knew they would retain. The sequel has shown that my surmises were well-founded, this proving to be the Comet we have lately

observed.

However, the claimed magnifications of 2010 and more raised a controversy. To the *Royal Society*, the high values seemed to be a wild exaggeration. In the paper ‘On the Parallax of the Fixed Stars’, read to the Society on 6 December 1781, Herschel even mentions 5400× and 6450×.[94] On 18 December, Watson wrote to Herschel that “some would think you fit for Bedlam when you talked about a power of 5400”.[95] In a letter to Watson of 7 January 1782, Herschel defended his position:[96] “Seeing is in some respect an art, which must be learned.” He was backed by Aubert, writing on the 22nd: “a little time will clear up the matter and if it lays in my power you shall not be sent to Bedlam alone, for I incline much to be of the party”.[97] The London amateur astronomer also used powers up to 2500×.

With the discovery of a new planet, Herschel became known in the scientific community. His name was a mystery, however. In 1781, Johann Elert Bode wrote a longer article about the object in the *Berliner Jahrbuch*, titled ‘About a moving star, discovered in the present 1781st year, which one can take for a planet moving beyond the orbit of Saturn and so far unknown’. The author collected amusing versions of Herschel’s name:[98]

In the Gazette Littéraire of June, 1781, this worthy man is called *Mersthel*; in Julius’ Journal Encyclopédique, *Hertschel*; in a letter from Mr. Maskelyne to M. Messier, *Herthel*; in another letter of Maskelyne’s to Herr Mayer, at Mannheim, *Herrschell*; M. Darquier calls him *Hermstel*. What may his name be? He must have been born a *German*. [In the *Connoissance des Temps* for 1784 he is called *Horochelle*.]

Herschel discovered Uranus three months after opposition, showing a magnitude of 5.6 and 3.7" diameter. Thus, in his telescope, the planet appeared as a small bright disk, very different from a star. It is astonishing that he found it a whopping 3.5° from 4.2 mag H Geminorum, the star he used to identify the position. Considering that the field of view of his standard eye-piece was only 4.5′, a distance of 3.5° equals 45 field-diameters.[99] Of course, a magnification of 227 was perfect to check if a catalogued star was double, but not suitable for inspecting larger areas – but Herschel

did just that.[100]

It is interesting that Herschel had been in the Gemini/Taurus region three times before. On 6 October 1779, β and ζ Tau were observed, a day later μ and η Gem, and on 24 September 1780 he again viewed β and ζ Tau. Ironically, the minimum distance to Uranus was just 3° for ζ Tau in 1779, i.e. even less than the 3.5° to H Geminorum on the discovery date (the distances for the other dates were 6° to 10°).

After 19 April, the Gemini/Taurus region got too low in the west. Herschel caught the 'comet' again in the eastern sky in the morning hours of 1 September: "My comet is not in the place I saw it last. I see it well defined with 227." It was in Gemini, 7.9° east of the discovery position. However, concerning the rediscovery, he was beaten by the Berlin astronomer Bode, writing to Herschel on 9 July 1783:[101] "You know perhaps that I was the first person in Germany to see the new star; this was on 1st August 1781."

On his 43rd birthday, on 15 November 1781, Herschel received a letter from Joseph Banks, President of the *Royal Society*, that the prestigious *Copley Medal* was awarded to him for the discovery of a 'new star'. He travelled to London, where he got the medal on 6 December and was elected a Fellow of the *Royal Society* (FRS) at the same time. In his laudation, Banks said:[102]

In the name of the Royal Society I present to you this gold medal [Copley Medal], the reward which they have assigned to your successful labors, and I exhort you to continue diligently to cultivate those fields of science which have produced to you a harvest of so much honor. Your attention to the improvement of telescopes has already amply repaid the labor which you have bestowed upon them; but the treasures of the heavens are well known to be inexhaustible. Who can say but your new star, which exceeds Saturn in its distance from the sun, may exceed him as much in magnificence of attendance? Who knows what new rings, new satellites, or what other nameless and numberless phenomena remain behind, waiting to reward future industry and improvement?

Herschel observed his 'comet' nine times until the end of 1781.[103]

It is worth mentioning that prior to the discovery on 13 March 1781, he had no experience with comets. Though there were four from 1774 to 1779, none was observed by him and it is not surprising that his first encounter with a comet on 21 November 1781 generated confusion.[104] The object was called ‘comet Pigott’ by him, though discovered by Pierre Méchain on 9 October.[105] Herschel made two sketches. The first shows the object, but not the second, even though it was entitled ‘Mr Pigotts Comet’.[106] This was later crossed out and replaced by ‘Georgium Sidus’ – the sketch clearly shows Uranus!

The ‘comet’ was finally named in July 1782. Herschel, inspired by a remark of Banks, that the object should in some way be dedicated to King George III, created ‘Georginum Sidus’.[107] Not sure, about the correct wording, he asked William Watson for help. The friend from Bath replied that, due to historic reasons, “the star should be called not ‘Georginum Sidus’ but ‘Georgium Sidus’”.[108] Herschel wrote a letter to Banks to propose this name.[109] Bode was not amused by this choice: “I have proposed the name Uranus for the new planet as I thought that we had better stick to mythology and for several other reasons.”[110] Bode also checked the relevant star catalogues for earlier observations of Uranus. He found two. In 1784 he revealed that Flamsteed had already seen the planet on 23 December 1690, listed in the *British Catalogue* as the 34th star in Taurus (34 Tau). He also noticed that Tobias Mayer had observed the planet on 25 September 1756 with his 6-foot Bird quadrant in the course of his measurements for the *Catalogue of Zodiacal Stars*. The object is entered as number 964.[111]

A curiosity happened on 30 January 1782. Now observing for his third star review, Herschel again inspected H Geminorum and its vicinity with 460$\times$:[112] “Looking at the small stars I discovered one very like my new star or Planet only differing a little in colour from it as I thought. I looked immediately for the new star and to my surprise found this was the same. Not having seen it these 10 days it had changed place so much that I did not expect it where I found it. This observation shews that had I not discovered it last March I should have found it out now.” It is not known what Herschel actually saw. Uranus was 1.5° northeast of H Geminorum at that time.

Calculations of Anders Lexell in autumn 1781 had already yielded a circular orbit beyond Saturn – a clear indication of a planet.[113] On 6 February 1782, Herschel believed to have seen a satellite of Uranus: "A very obscure star precede the comet about 1'." On the 7th, he first spoke of a 'planet', remarking that his "observations were made with a view of detecting a satellite, as it now appears this new star [Uranus] is probably a primary Planet of our Solar System." On 29 August we read: "I saw my Planet full as well defined with 460 as Jupiter would have been at that altitude with the same power."[114] When Herschel discovered two Uranian moons in 1787, he titled the published report: 'An Account of the Discovery of two Satellites of the Georgian Planet'. The previous name 'Georgium Sidus' now appeared in a new variant and was kept for some time.

Finally, an important remark about Herschel's epochal discovery. Obviously, due to the systematic approach of the second star review, the time was right for the planet. On 5 September 1782, he wrote to Lalande[115] that "the discovery was not owing to chance" since the planet "must sooner or later fall into my way; and as it was that day the turn of the stars in that neighbourhood to be examined I could not very well overlooked it; my telescope being so distinct and powerful that the moment I saw it I must know it not to be a fixt star". In a letter to Charles Hutton, he wrote:[116] "It has generally been supposed that it was a lucky accident that brought this star into my view; this is an evident mistake. In the regular manner I examined every star of the heavens, not only of that magnitude but many far inferior, it was that night *its turn* to be discovered."

This raises the legitimate question: Why didn't Herschel also find Neptune in his observing campaigns? At the time of his second and third review, the 8th planet was located in the area near γ Vir (Porrima), just north of the ecliptic. Working backward from what we know now, we find there were four conjunctions of Neptune with brighter stars less than 3° distant, during that period.[117] The first happened on 21 November 1781 when Neptune was 1.3° south of γ Vir.[118] On 9 February 1782, the planet was 1.4° south of the star and on 17 February, it was 1.4° northwest of a double star found on that night.[119] The last conjunction appeared on 28 May

1783, when Neptune had another rendezvous with γ Vir (1.3° south). At 460×, the 7.9 mag object with 2.3" diameter would not have escaped Herschel's keen eyes.[120]

1.4. The third star review: a flood of new double stars

1.4.1. The *Atlas Coelestis* and Flamsteed numbers

Based on what he had learned from the second review, Herschel started another one. The campaign took about 23 months and again was performed with his standard 7-foot reflector (aperture 6.2 inches). It began on 22 October 1781 and ended on 26 September 1783. In the middle of that period, on 2 August 1782, Herschel moved from Bath to Datchet near Windsor.[121] The third review was different both in respect to the number of stars and the magnification. In 1783 Herschel wrote:[122]

My third review was with the same instrument and aperture, but with a distinct power of 460, which I had already experienced to be superior to 227, in detecting excessively small stars, and such as are very close to large ones […] This review extended to all the stars in Flamstead's [sic] catalogue, together with every small star about them, as far as tenth, eleventh, or twelfth magnitude, and occasionally much farther, to the amount of a great many thousands of stars.

Correlating the Harris maps with about 1200 labelled stars (mainly inspected in the second review), and the *British Catalogue*, which lists about 3000, he now set for himself some 1800 new targets – a massive undertaking. The organization of this new plan was strongly influenced by Herschel's purchase of Flamsteed's *Atlas Coelestis*.[123]

When was the atlas first used by him? The date can be derived from constellation names which are not found in the *British Catalogue,* but appear in the *Atlas Coelestis*. In Herschel's record for 16 July 1781, the name 'Ophiuchus' appears for the first time.[124] Formerly, the constellation was called 'Serpentarius', taken from the Harris

maps. He also now used ‘Cor Caroli & Chara’ (Canes Venatici) and ‘Corona Septentionalis’ (Corona Borealis). Thus, it is most likely that the atlas was purchased in July 1781. Herschel’s *Journal* entry for 12 October 1781, written in the final phase of his second review, reads: “Triangulum major by Fl[amsteed’s] Cat[alogue] & Atlas.” This implies: he possessed the atlas no later than that date. Moreover, in the opening entry of the third review (22 October) the stars in Monoceros were identified “by Flamsteed’s maps of Atlas Coelestis”. Of course, for a while Herschel used the Harris maps and the new atlas in parallel.

Just as he had done with telescope design, Herschel designed his observing plan by combining what he regarded as the key aspects of existing astronomical works to suit his own observational techniques and goals. An example is his use of Flamsteed star numbers (like 61 Cyg), astronomers are so familiar with today. As early as 21 September 1781 we read: “Hercules, 23. star by Flamsteed.”[125] But there is a problem! Although Flamsteed ordered the stars in each constellation by increasing right ascension (AR)[126], a numbering was not given. They do not appear in the *Atlas Coelestis* either. A recent investigation by the author has shown that Herschel introduced ‘Flamsteed numbers’ for his own use, simply adding them by hand to the stars in the *British Catalogue* (Figure 1-18).[127]

Flamsteed was a life-long hero of William – and even more of Caroline, who intensively studied the *British Catalogue* for her daily work on planning and evaluation of her brother’s observations. In 1789, he published a book about her examination of Flamsteed’s original observations. It was a basis for the standard work on the first Astronomer Royal, published by Francis Baily in 1835.[128] It contains a revised version of the *British Catalogue*. Both persons are portrayed in.

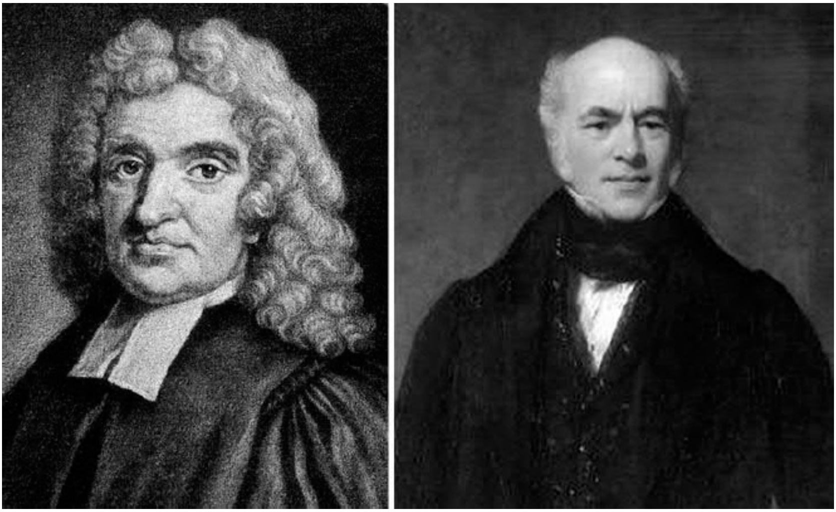


Figure 1-17: The first Astronomer Royal John Flamsteed (left) and Francis Baily, author of a revision of the *British Catalogue*.

Unfortunately, we do not have Herschel's copy of the *British Catalogue* – but we have his *Atlas Coelestis*.[129] It shows Flamsteed numbers, added to the stars on each chart with a pen – in Caroline's handwriting! The task is briefly mentioned in her second autobiography:[130] "Flamsteed's Atlas in which the stars had during the winter [1781/82] been numbered." Herschel's second catalogue of double stars (1785) gives a more detailed version:[131]

It will be required, that the observer should be furnished with FLAMSTEED'S Atlas Coelestis, which must have the stars marked from the author's catalogue, by a number easily added to every star with pen and ink, as I have done to mine. The catalogue should also be numbered by an additional column, after that which contains the magnitudes. I hope in some future editions of the Atlas to see this method adopted in print, as the advantage of it is very considerable, both in referring to the catalogue for the place of a star laid down in the Atlas, and in finding a star in the latter whose place is given in the former.

In Conſtellatione ARIETIS.

ORDO Ptol.	ORDO Tych.	STELLARUM Denominatio.	Bayer Cha.	Aſcenſio Recta. ° ′ ″	Diſtantia à Polo B. ° ′ ″	Longitudo. s ° ′ ″	Latitudo. ° ′ ″	Varia. Aſc.R. ′ ″	Varia. D. à P. ′ ″	Magnitud.	
				20 46 0	69 17 15	♈ 26 58 25	11 4 58 B	58 7	22 25	7.6	1
				21 25 45	71 15 25	26 48 15	9 1 26 B	57 52	22 19	7.6	2
				22 26 15	74 10 55	26 36 18	5 57 3 B	57 31	22 12	6	3
				22 51 15	74 36 55	26 49 4	5 23 59 B	57 28	22 07	7.6	4
1	1	Quæ in Cornu duarum præcedens	γ	24 8 30	72 14 45	28 51 0	7 8 58 B	58 02	21 55	4	5
2	2	Sequens & *Borea* eſt	β	24 23 30	70 43 55	29 37 59	8 28 16 B	58 22	21 50	3	6
				24 39 45	67 57 45	♉ 0 54 20	10 57 12 B	58 57	21 49	tel	7

Figure 1-18: First entries of the *British Catalogue* with ‘Flamsteed numbers’ (1 to 7 Ari), here added to the right by the author.

Later Herschel wrote: “Setting aside the letters entirely I use only numbers in all my observations, and these numbers are such as I have added with red ink both to the edition of 1725 of the British catalogue, and to the *Atlas Coelestis* taken from that catalogue, and printed in 1729.”[132] This is supported by an extract of Flamsteed’s catalogue, given in *Review No. 4* (January 1782). It describes Herschel’s modifications, made to prepare his third review.[133] The constellations are ordered alphabetically. The stars in it are listed by an increasing number in the first column ‘Fl.’ (Flamsteed); the second column gives the Bayer letter and the third is reserved for the brief observational result. An index gives the plate number in the *Atlas Coelestis* for each constellation.

Obviously, Caroline finished the numbering in the *Atlas Coelestis* in late January. This is seen by William’s observations. Prior to 30 January, mainly stars with Bayer letters were inspected. After that date, we see that Flamsteed numbers are used. It is interesting that the new notation started with 1 (H) Geminorum, the reference star for Uranus. Herschel observed the nearby stars 2, 3, 4, 5, 6, η (7), 8, 9, 10 and 11 (Figure 1-19).

Based on the analysis of his *Atlas Coelestis*, it is likely that Herschel terminated the second review in October 1781 due to the new atlas. With a much more detailed source in his hand, it was time for a third review.

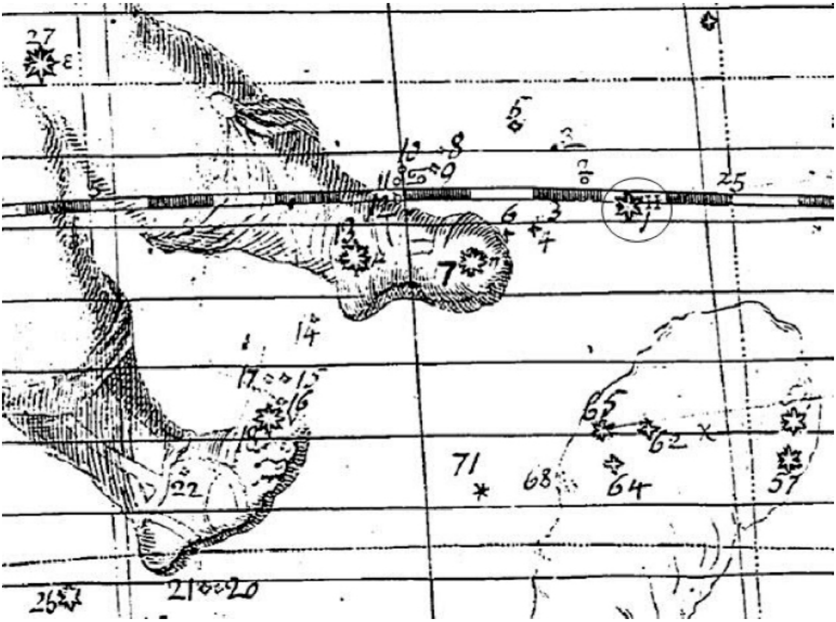


Figure 1-19: William Herschel's 'Flamsteed number', inserted by Caroline in his copy of the *Atlas Coelestis*. The part of Gemini, including 1 (H) Geminorum (small circle), is shown; the stars at lower right belong to Orion (compare Figure 1-16).

During the new campaign, Herschel had interesting guests. King George III visited Bath three times in 1782: on 30 August (viewing M 31 and M 11), 3 September (double stars) and 1 December 1782 (Uranus with the 10-ft, inspecting the 'small 20-ft'). He returned on 28 April 1783 (Uranus, M 35). On 1 January 1783, Herschel received James Lind to see Uranus with the 10- and small 20-ft.[134] Joseph Banks visited Bath on 30 April to see the same object. The pole star was shown to 'Mr Hawkings' on 4 July 1783 with the 7-ft.[135]

1.4.2. Mayer's double star catalogue and the move to Datchet

In the first night of the third review, 22 October 1781, Herschel made a tour de force through 14 constellations: Corona Borealis, Boötes, Serpens, Hercules, Aquila, Equuleus, Lyra, Cetus, Triangulum, Eridanus, Taurus, Orion, Lepus and Monoceros. Guided

by the *Atlas Coelestis*, nine double stars were found; the most prominent was γ Lep. In between, he had time to visit Uranus, 1.2° northeast of μ Gem: "Comet perfectly defined certainly no coma, fine bright steady light of the colour of Jupiter or apparently to the Moon's light, certainly larger than last year by the appearance."[136] The cold night ended at 8 am: "The frost seems to be no kind of hindrance to seeing, for my tube is all over with ice, or rather white frost and yet I see very well."

From October until the end of 1781, Herschel observed in 18 nights, finding 25 double stars. Among them was Aldebaran on 19 December, which 10th magnitude companion is 97" distant. In late November, he followed Méchain's comet (aka 'Comet Pigott'), moving along the Aquila/Delphinus border; Uranus was observed again.

In December, Herschel received two publications, sent by his Bath friend William Watson, which would be very useful for his observations. The first was Christian Mayer's catalogue of 72 double stars, published in 1779 – the first of its kind.[137] Herschel had reached this number on 5 December 1779; when he received Mayer's work, his score was already grown to 279. The observational results of the Mannheim astronomer were helpful in the making of his own catalogue of double stars, to appear in 1782 (see section 1.5.1).

The other gift was second *Messier Catalogue* of nebulae and clusters, published in 1780. It contains the objects M 1 to M 68; in the appendix M 69 and M 70 are added.[138] For now, though, double stars were Herschel's priority, so Messier's catalogue had to wait until August 1782, after the move from Bath to Datchet.

1782 was a busy year, but occasionally William found time to show double stars to his siblings Caroline and Alexander[139], like ζ Cnc on 20 January ("they saw exactly as I did and marked them upon paper"). He also observed stars with extreme magnification: on 29 March, Vega and Polaris were viewed with 6450× and on 14 April the pole star was even tried with 6651×.[140] Such observations were very difficult. The objects had to be found in a field of view of only 20" – and held there against the sky motion (of course, no tracking was needed for Polaris). Herschel rarely used Huygenian

(double-lens) eye-pieces and his highest powers were all achieved with single convex lenses (a collection is seen in Figure 1-20). He also tried concave lenses, but they cannot be used with a micrometer.

Figure 1-20: A collection of Herschel's eye-pieces. He preferred the single lens design. The short ones (small focal length) are for high powers.

King George III, a great admirer of astronomy, was well-informed about Herschel's successful work, through his visits at Bath, oral messages and publications, handed out to him. He was especially impressed by the discovery of a new planet, which bore his name: 'Georgium Sidus'. The King had installed his own observatory at Kew Gardens near London, completed in 1769. When his 'Royal Astronomer', Stephen Charles Demainbray, died there in 1782, whether to install Herschel as his successor was discussed.[141] But to the joy of William, who had different plans, this engagement did not come about. Even so, he was invited to Windsor Castle for a Royal star party. On 2 July 1782, he brought his 7-ft, staying at the castle for three days to entertain the King and his family. Herschel noted:

This evening His Majesty and all the Royal Family observed Jupiter, Saturn and several double stars with my 7ft Reflector. His Majesty had ordered three of his instruments (viz a 10 or 12 ft Achromatic

of Dollond's a 3½ Achromatic a Short's reflector) to be brought in order that they might be compared with mine; my Telescope shewed the heavenly bodies much more distinct than the other Instruments. His Majesty saw ε Bootis with [magnification] 460 and the Pole Star with 932. The Queen [Sophie Charlotte] found the Newtonian construction very convenient.[142]

On the 3rd, Herschel wrote to Caroline at Bath:[143] "My instruments gave a great satisfaction; the King has very good eyes and enjoys Observations with the Telescope accordingly." Obviously, the successful visit convinced him to look for a new home near Windsor Castle. Only a month later, Herschel would move from Bath to Datchet.[144]

Herschel's diary entry for the departure day, 2 August 1782, reads:[145]

This day the wagon brought my astronomical apparatus &C. arrived very safely and was delivered at my house, of which I took possession and where in a few days I began to erect my [small] 20 feet telescope. My Brother [Alexander] and sister were with me, the former on visit, the latter to be my assistant in astronomy, in which capacity she had already acted at Bath. I employed myself now so intirely in astronomical observations, as not to miss a single hour of star-light weather, for which I used either to watch myself or to keep up somebody to watch; and my leisure hours in the day time were spent in preparing and improving telescopes.

The next day, Herschel resumed his double star observations, looking-up in the "very fine evening" the close pair ε Boo, found in 1779.

Due to the move to Datchet, about 100 miles east of Bath, no observations were made between 23 July and 3 August. On 20 August, Herschel wrote: "I tried my [small] 20ft against the 7ft and found it much superior."[146] Occasionally, larger reflectors were tested on stars, as Herschel began to search for fainter and fainter objects. On 2 September, the 10-ft was pointed at ζ Aqr with 235×. On 11 November, the small 20-ft was equipped with a new mirror ("it discovers an astonishing number of small stars").

However, Herschel's new site on the left bank of the Thames was not ideal for his telescopes. The humid air often caused the lenses to fog up and sometimes the low plain was subject to flooding. Fortunately, he had built a platform, which served as an 'island' to protect the instruments from water damage. In a paper of 1803, Herschel described various phenomena in the chapter 'Observations and experiments relating to the causes which often affect mirrors, so as to prevent their showing objects distinctly'.[147] Phenomena, like moisture, fog, frost, hoar-frost, dry air, storms and the aurora are mentioned. Herschel had experienced all these activities and overcome almost all of them, sometimes in a surprisingly matter-of-fact manner:

Sept. 7, 1782. I viewed the double star preceding 12 Camelopardalis with 932. In this, and several mentions of some nights which I have lately had, the condensing moisture on the tube of my telescope has been running down in streams; which proves that damp air is no enemy of good vision.

Dec. 28, 1782, 17^{h} 30'. The water condensing on my tube keeps running down; yet I have seen very well all night. I was obliged to wipe the object glass of my finder almost continually. The Specula [main mirrors] however are not in the least affected by the damp. The ground was so wet that, in the morning, several people believed there had been much rain in the night, and were surprised when I assured them there had not been a drop.

Feb. 19, 1783. I have seen perfectly well till now that a frost is coming on; though Datchet Common, which is just before my garden, is all under water; and the grass on which I stand with my telescope is as wet as possible.

That Herschel handled his telescopes in Datchet fairly well with regard to the weather did not mean, however, that he was equally careful with his own health. Years later John reported:[148] "when the waters were out round his garden, [William] used to rub himself all over face and hands &c., with a raw onion, to keep off the infection of ague, which was then prevalent; however he caught it at last."

In the course of 1782, Herschel discovered the amazing number of

306 double stars! Two were found while observing at the Royal Observatory, Greenwich, on 29 May and 1, 2 & 6 June. The 7-ft reflector with 6.2 inches aperture had already been moved from Bath on 20 May. Herschel was able to demonstrate the superior power of his instrument against Maskelyne's telescopes. The Astronomer Royal used an achromatic refractor of 46 inches focal length and a 6-foot reflector made by Short. William's friend Alexander Aubert joined the exclusive observing session. Herschel wrote:[149] "I can now say that I absolutely have the best telescopes that were ever made."

On 2 June, Herschel saw that the star σ^2 UMa was double, and on the 6th, he found an unequal pair about a degree northeast of π^1 UMa.[150] Maskelyne, Aubert and three other persons visited the Herschels on 15 June to observe double stars with the 7-ft.[151]

At the new site – and despite the poor environmental conditions – Herschel worked with even more energy. Observations often lasted ten or twelve hours at a time. Along with double stars he occasionally encountered other interesting stars, for instance, μ Cep, known as Herschel's Garnet Star (see section 1.6).

Herschel discovered 117 double stars in 1783; 53 nights could be used for observing (in the record year 1782 we have 306 double stars in 72 nights). The third review ended on 26 September. In reviewing all Flamsteed stars, he often examined 400 stars in a night. Here are a few interesting observations. On 6 January 1783, Herschel inspected three of Mayer's double stars, nos. 64, 70 and 72. On 31 January, he found his most southern exemplar, 1.5° southeast of 2 Cen at δ = -35°. At 4:15 am it was only 3° above the horizon – an incredible observation! A few minutes earlier, 3 Cen had already been found to be double at 4.5° altitude. Table 1-7 presents the statistical data of the third review (compare Table 1-6).

Subject	Location / number	Date
most northern CON	Ursa Minor	
most northern DS	Polaris = IV 90 (SAO 2556) at δ = +89°	12 Oct. 1782
most southern CON	Centaurus, Columba, Lupus, Pisces Austrinus, Puppis	

	('Vela')	
most southern DS	V 124 (SAO 204955) at δ = -35° (Centaurus)	31 Jan. 1783
most visited CON	Orion (50), Leo (44), Hercules, Perseus, Gemini (all 43)	
last visited CON	Columba (1), Lupus (1), Centaurus (2)	
max. number of CON/ night	18	6 Nov. 1782
max. number of DS/ night	14	9 Feb. 1782

Table 1-7: Statistic for the third review (CON = constellation, DS = double star). Sextans, Lupus, Columba and Centaurus were not observed in the second review.

Table 1-8 summarizes the main data of Herschel's three star reviews.152 As discussed above, the information for the first is pretty poor. The results of his search for double stars were the basis for the published catalogues, treated in the next section.

Subject	First review	Second review	Third review
period	1778	17 Aug. 1779 – 20 Oct. 1781	22 Oct. 1781 – 26 Sep. 1783
location	Bath	Bath	Bath, Datchet (since 2 Aug. 1782)
months	6?	26	23
nights	?	225	261
star selection	Name, Bayer	Bayer, Flamsteed + vicinity	Flamsteed + vicinity
magnitude limit	4 mag	7–8 mag	8–9 mag
map or atlas	Senex/Harris	Senex/Harris	*Atlas Coelestis*
reflector (power)	7-ft / 4-in (222×)	7-ft / 6.2-in (227×)	7-ft / 6.2-in (460×)
new double stars	1 (Castor)	251 (Polaris, ε Lyr etc.)	447 (γ Leo, γ Lep etc.)
in 1st catalogue	1	251	15
in 2nd catalogue	-	-	432
new nebulae	-	5	7

Table 1-8: Basic data of Herschel's three star reviews. In the first nights of the second review, he still used the old 7-ft reflector with a 4-inch mirror. Herschel found most of the best double/multiple stars in the sky.

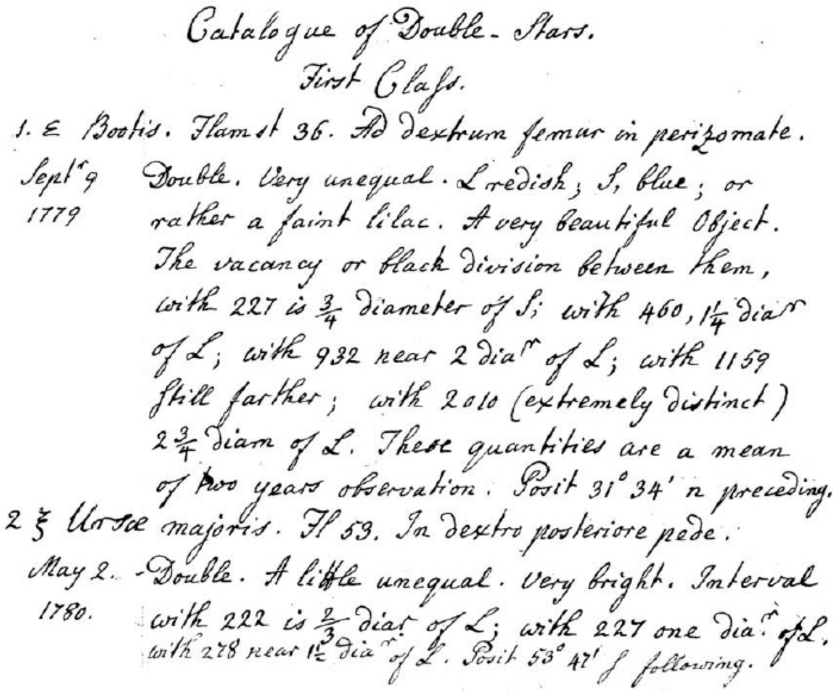
1.5. Herschel's two catalogues of double

stars

1.5.1. The first catalogue

Herschel introduced the world to his work on stellar astronomy in his first catalogue of double stars, the manuscript of which is dated 25 December 1781 (Figure 1-21).[153] The 'Catalogue of Double Stars' was communicated to the *Royal Society* by his friend William Watson Jr and read on 10 January 1782. It appeared in Volume 72 of the *Philosophical Transactions*.[154] The catalogue lists 269 cases, "not only double stars, but also those that are treble, double-double, quadruple, double treble, and multiple". 251 cases came from second review, 15 from the third, one from the first (Castor) and two prior to it (θ Ori, Mizar).

For identification, Herschel used Bayer letters and his 'Flamsteed numbers' (abbreviated 'FL.'). New objects without a number are identified in relation to known stars (no coordinates are given in the catalogue). For instance, the last discovered double star (II 38), a pair in southern Boötes, is localized by "the most north and largest of three in line, south following FL. 15 (Bootis)". It was found on 24 December 1781 in the second review (Figure 1-22). Herschel also gives the comparative 'sizes' (brightness) of the stars, using the terms 'equal' and 'unequal'; the latter in different grades: 'little', 'pretty', 'considerably', 'very', 'extremely' and 'excessively'. Colours are mentioned and the position angle (orientation, see Figure 1-23) is quantified in degree and minute.



Catalogue of Double-Stars.
First Class.

1. ε Bootis. Flamst 36. Ad dextrum femur in perizomate.
Sept^r 9 1779 Double. Very unequal. L redish; S, blue; or rather a faint lilac. A very beautiful Object. The vacancy or black division between them, with 227 is $\frac{3}{4}$ diameter of S; with 460, 1$\frac{1}{4}$ dia^r of L; with 932 near 2 dia^r of L; with 1159 still farther; with 2010 (extremely distinct) 2$\frac{3}{4}$ diam of L. These quantities are a mean of two years observation. Posit 31° 34′ n preceding.

2 ξ Ursæ majoris. Fl 53. In dextro posteriore pede.
May 2. 1780. Double. A little unequal. Very bright. Interval with 222 is $\frac{2}{3}$ dia^r of L; with 227 one dia^r of L. with 278 near 1$\frac{1}{2}$ dia^r of L. Posit 53° 47′ f following.

Figure 1-21: The first entries in Caroline's manuscript of the first catalogue of double stars: I 1 = ε Boo and I 2 = ξ UMa.

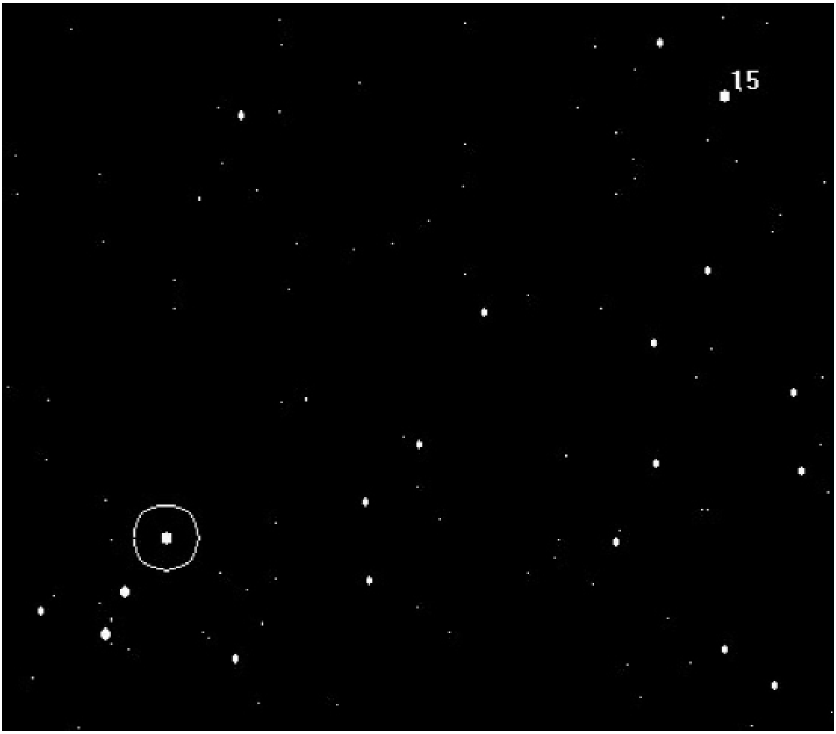


Figure 1-22: The double star II 38 in Boötes, 2.7° southeast of 15 Boo (5.3 mag), is the last discovered object entered in Herschel's first catalogue (see text).

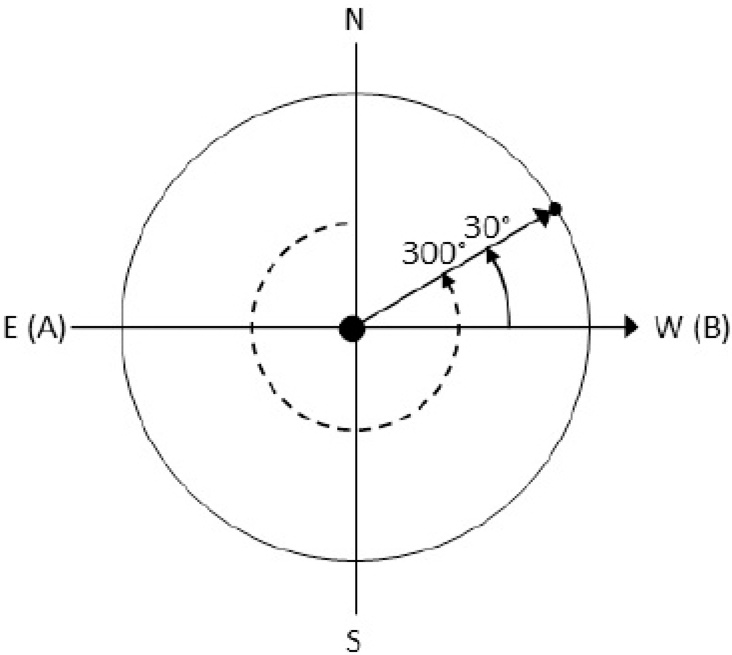


Figure 1-23: Herschel's definition of the position angle. It is measured from the direction of the sky motion (A → B) towards the north; 30° in this case (north preceding). The modern definition, based on the north direction, gives 300° (dashed angle).[155]

To characterize the separation of double/multiple stars, Herschel has created six classes (Table 1-9).[156] The class system was also used to designate the objects: following the Roman numeral for each class, each entry is given an Arabic number based on its discovery date, earliest to later. Class I contains the closest and most difficult pairs. With the standard 7-ft reflector (6.2-inch), Herschel could resolve double stars down to about 1", which is not far to the theoretical limit.

Class	Separation	Numbers	Corresponding dates	Prominent stars
I	most difficult	1 – 24	9 Sep. 1779 – 21 Nov. 1781	ε Boo (I 1)
II	less than 5"	1 – 38	8 Apr. 1778 – 25 Dec. 1781	Castor (II 1)
III	5" to 15"	1 – 46	9 Apr. 1774 – 22 Oct. 1781	Mizar (III 2)
IV	15" to 30"	1 – 44	17 Aug. 1779 – 22 Dec. 1781	Polaris (IV 1)
V	30" to 60"	1 – 51	29 Aug. 1779 – 23 Nov. 1781	Albireo (V 5)
VI	greater than 60"	1 – 66	19 Oct. 1779 – 19 Dec. 1781	Aldebaran (VI 66)

Table 1-9: Separation classes and object numbers in Herschel's first catalogue of double stars.

A few of the dates given, however, are incorrect. Two prominent class II objects, the Trapezium (θ Ori = III 1) and Mizar (ζ UMa = III 2) were both first observed on 9 April 1774, but the catalogue gives 11 November 1776 and 17 August 1799, respectively. Also, 9 August 1779 for δ Her (V I) is wrong; it should be the 29th (in this night also β and ζ Lyr were resolved). The same goes for Mira (VI 1): the date should read 19 October 1779 instead of 20 October 1777. There is one duplicate entry in the first catalogue. The double star ε Mon was found first on 15 February 1781 and listed as III 29, then found again on 20 October that year and listed as III 44. Dreyer mentions this case in the *Scientific Papers*.[157]

While the manuscript was being written in December 1781, Herschel received Mayer's catalogue of 72 double stars, published in 1779.[158] He immediately studied its content and wrote a 'Postscript to the Catalogue of Double Stars'. First, the different ambitions are treated. While Mayer was mainly interested in the proper motion of stars, Herschel's focus was on parallax. The latter needed the detection of close pairs, using high magnification, which the 7-ft easily offered. Though Mayer's instrument was optically inferior, it brought better positions: a mural quadrant, equipped with a Dolland refractor of 3 inches aperture and 8 feet focal length. Herschel wrote: "It can hardly be expected, that a power of 70 or 80 would be sufficient to discover those curious stars that are contained in the first class of my catalogue; so, it is not strange that they should have entirely escaped Mr. Mayer's notice."

Herschel defended his term 'double star':[159]

I have used the expression *double-star* in a few instances of the sixth class in rather an extended signification: the example of FLAMSTEAD [sic], however, will sufficiently authorize my application of the term. I preferred that expression to any other, such as Comes, Companion, or Satellite; because, in my opinion, it is much too soon to form any theories of small stars revolving round large ones, and therefore I thought it adviseable carefully to avoid any expression that might convey that idea. I am very well persuaded, FLAMSTEAD, who first used the word Comes, meant it

only in a figurative sense.

Herschel writes in his catalogue that 227 of the 269 stars “to my present knowledge have not been noticed by any person”; 33 Mayer objects are marked (*), seven by others (†). However, four more appear in Mayer’s list: II 10 (σ Ori) = no. 12, III 31 (100 Her) = no. 46, IV 13 (83 Leo) = no. 26 and IV 28 (near γ Gem) = no. 16. This oversight is due to Herschel’s ‘coordinate-free’ listing and the fact that Mayer gives only the constellation if there is no Bayer letter. Herschel was aware of this, writing: “Among the stars which are not marked, will be found several that have been observed by Mr. Mayer; but, on comparing them together, it will be seen, that they are observations of different small stars”. The identification problems are due to the different ways the two men recorded their observations. The ‘amateur’ Herschel was often criticised by professional astronomers (at Greenwich, Oxford etc.) for his loose style of determining and presenting positions by a small chart or textual description. These persons were educated in classical astronomy, meaning ‘astrometry’ at that time.[160] By their view, positions had to be measured by mural circles or sophisticated transit instruments – alternative methods were ‘unscientific’ and below their dignity.

Comparing the manuscript, dated 25 December 1781 (and including the postscript), and the published paper there are differences.[161] During the proof read, several corrections were made (see Table 1-12). Volume 72 of the *Philosophical Transactions* was eventually on the market in June 1782.

1.5.2. The second catalogue

Herschel’s second catalogue lists 434 objects. The class numbers were continued (Table 1-10).

Class	Numbers	Total	Corresponding dates
I	25 – 97	73	20 Jan. 1783 – 24 Sep. 1783
II	39 – 102	64	2 Feb. 1782 – 27 Sep. 1783
III	47 – 114	68	27 Dec. 1781 – 23 Jan. 1784
IV	45 – 132	88	27 Dec. 1781 – 6 Aug. 1783
V	52 – 137	86	27 Dec. 1781 – 22 Sep. 1783
VI	67 – 121	55	27 Dec. 1781 – 18 Aug. 1783

Table 1-10: Objects in Herschel's second catalogue of double stars, ordered by their separation class.

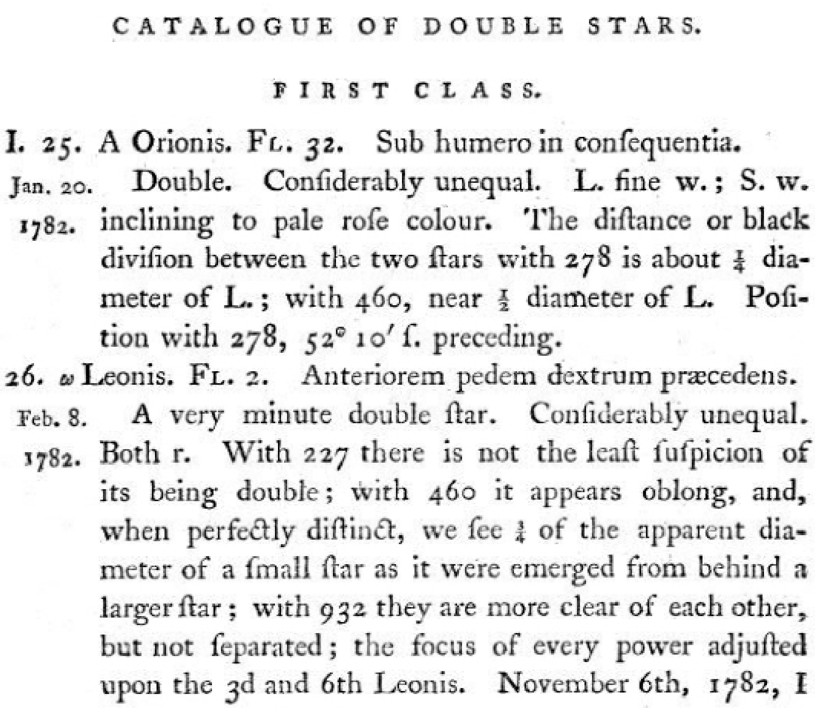
It is interesting to compare the dates of the two catalogues (Table 1-11). For the first catalogue, the manuscript was finished one day after finding the last object. However, for the second catalogue, there was a delay of about nine months.[162] Why this difference? The reason for the fast completion of the first catalogue was Herschel's paper 'On the Parallax of the Fixed Stars', developing the idea of determining parallax with the aid of close star pairs. It had been read to the *Royal Society* on 6 December. He was therefore forced to publish the associated database almost immediately following the theoretical paper. In fact, in Vol. 72 of the *Philosophical Transactions* Herschel's publications on the parallax and the first catalogue immediately follow one another.

Event	First catalogue	Second catalogue
first observation	9 April 1774	27 December 1781
last observation	24 December 1781	23 January 1784
Caroline's manuscript	25 December 1781	1 November 1784
paper read to the *Royal Society*	10 January 1782	9 December 1784

Table 1-11: Relevant dates for the two double star catalogues.

What caused the delay in the second catalogue? It was supposed to represent the results of Herschel's third review, ending on 26 September 1783. However, the catalogue lists two later objects: II 102 (near 29 Ori) on 27 September 1783 and III 114 (near 16 Mon) on 23 January 1784. The latter was discovered in sweep 99, using the 20-ft reflector. But why did Herschel include this double star and not the 15 others, found between 24 January and 1 November

1784 in the following sweeps (up to no. 279)? Actually, the star near 16 Mon was seen on 26 December 1783, when he discovered the nebula NGC 2261 in sweep 67. However, the duplicity was not noticed that night. The time gap of about a year between the last double star found with the 7-ft reflector and the manuscript date is remarkable, but can be explained: the intensive sweep campaign, starting on 29 October 1783, simply left no time to work on the manuscript. It was read to the *Royal Society* on 9 December 1784 and appeared in Volume 75 of the *Philosophical Transactions* (Figure 1-24).[163]



CATALOGUE OF DOUBLE STARS.

FIRST CLASS.

I. 25. A Orionis. Fl. 32. Sub humero in conſequentia.

Jan. 20. 1782. Double. Conſiderably unequal. L. fine w.; S. w. inclining to pale roſe colour. The diſtance or black diviſion between the two ſtars with 278 is about ¼ diameter of L.; with 460, near ½ diameter of L. Poſition with 278, 52° 10′ ſ. preceding.

26. ω Leonis. Fl. 2. Anteriorem pedem dextrum præcedens.

Feb. 8. 1782. A very minute double ſtar. Conſiderably unequal. Both r. With 227 there is not the leaſt ſuſpicion of its being double; with 460 it appears oblong, and, when perfectly diſtinct, we ſee ¼ of the apparent diameter of a ſmall ſtar as it were emerged from behind a larger ſtar; with 932 they are more clear of each other, but not ſeparated; the focus of every power adjuſted upon the 3d and 6th Leonis. November 6th, 1782, I

Figure 1-24: The first entries of Herschel’s second double star catalogue, published 1785. Note the Latin description of the position (following Bayer and Flamsteed).

As in the case of the first catalogue, there are also differences between the manuscript and the published version for the second. Table 1-12 shows the numbers of objects in the six classes. Obviously, objects were added/deleted and shifted between the

classes. The issue is complex and will not further treated here.

	First catalogue		Second catalogue	
Class	Manuscript	Publication	Manuscript	Publication
I	24	24	64	73
II	39	38	51	64
III	47	46	68	68
IV	47	44	83	88
V	46	51	88	86
VI	68	66	51	55
Sum	**271**	**269**	**405**	**434**

Table 1-12: Differences between the two catalogues, concerning the number of objects in the six classes.

About the accuracy of the second catalogue, Herschel writes that "the present collection [is] much more perfect than the former; almost every double star in it having the distance and position of its two stars measured by proper micrometers; and the observations have been much oftener repeated". Instead of using the standard magnification (460 ×), "the measures of the distances were all taken with a parallel silk-worm's-thread micrometer and a power of 227." Herschel invented his 'revolving-wire micrometer' about 1779. It did not differ from the classical 'filar micrometer', but spiderlines were substituted for the original silk fibres. For measuring, the distances of the wider classes of double stars, he devised a 'lamp-micrometer' in 1782; while those of the closest pairs were estimated in terms of the discs of the components.164

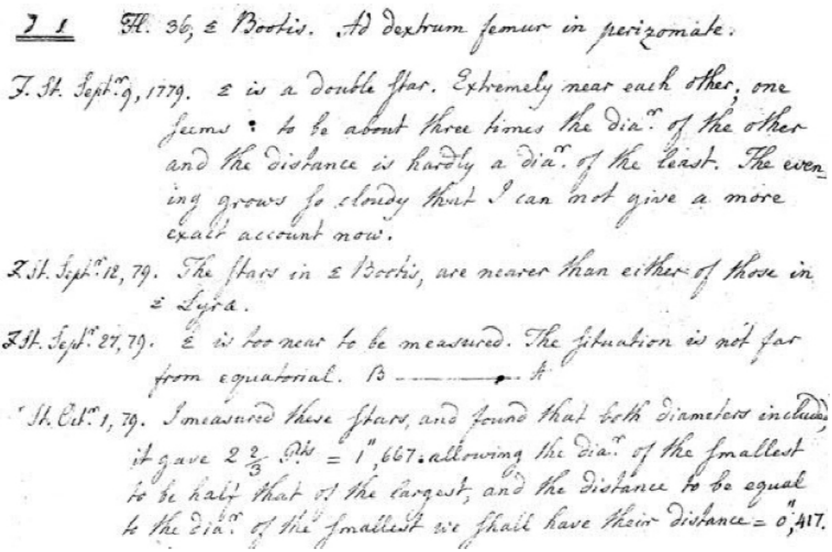
Figure 1-25: A collection of Herschel's micrometer eye-pieces.

With the alt-azimuthally mounted reflector, Herschel had to use the method of 'star-hopping' to find an object.[165] To get distances on the sphere, he had equipped the eye-piece of the finder with a diaphragm to give a constant field of 2°; the central crosshair then marked sectors of one degree. In his paper, he describes the method of marking a position for I 32, found on 3 April 1782: the pair is "about ¾ degree south preceding 44 Lyncis; in a line parallel to θ

Ursae majoris and the 39th of Lyncis”.[166] Herschel also mentions the fact of field inversion and further recommends that

> the observer should be furnished with FLAMSTEED’S *Atlas Coelestis*, which must have stars marked from the author’s catalogue, by a number easily added to every star with pen and ink, as I have done to mine. The catalogue should also be numbered by an additional column, after that which contains the magnitudes. I hope in some future editions of the Atlas to see this method adopted in print, as the advantage of it is considerable, both in referring to the catalogue for the place of a star laid down in the Atlas, and in finding a star in the latter whose place is given in the former.

As we have seen, the work with ‘pen and ink’ was done by Caroline. She was also responsible for the extensive collection of all double star observations.[167] Each object (I 1 to VI 121) is given a sheet, listing the observing records by date (Figure 1-26). This not only includes those made during the reviews, but also all later ones. Moreover, it is documented when an object was seen in a sweep or in the period after the sweep campaign.


I 1 Fl. 36, ε Bootis. Ad dextrum femur in perizomate.

7. ft. Sept.r 9, 1779. ε is a double star. Extremely near each other, one seems : to be about three times the dia.r of the other and the distance is hardly a dia.r of the least. The evening grows so cloudy that I can not give a more exact account now.

7. ft. Sept.r 12, 79. The stars in ε Bootis, are nearer than either of those in ε Lyra.

7 ft. Sept.r 27, 79. ε is too near to be measured. The situation is not far from equatorial. B ——• A

7 ft. Oct.r 1, 79. I measured these stars, and found that both diameters included it gave 2 2/3 Pts = 1",667: allowing the dia.r of the smallest to be half that of the largest, and the distance to be equal to the dia.r of the smallest we shall have their distance = 0",417.

Figure 1-26: Part of Caroline’s sheet for the double star ε Boo (I 1); the early observations are shown, made in the second review (September/October 1779) and recorded in the *Fixt Stars*.

Did Herschel achieve his aim that the parallax of fixed stars could be determined by double stars? The most promising cases were those with (1) a small distance, which means objects of class I and II, and (2) a large magnitude difference (possibly with a bright main star). The two catalogues offer 14 exemplars in class I and 28 in class II. Table 1-13 shows the best cases. Herschel's chief subject was ε Boo.

Object	Star	Dist. (")	V (A)	V (B)	ΔV	Observing period	Obs	CH
I 1	**ε Boo**	1.6	2.6	4.8	2.2	9 Sep. 1779 – 26 Mar. 1803	77	
I 28	**γ Leo**	3.0	2.4	3.6	1.2	9 Feb. 1783 – 11 May 1809	44	T
I 36	**ζ Her**	1.0	2.5	5.4	2.9	18 Jul. 1782 – 28 May 1803	17	T
I 94	δ Cyg	2.3	2.9	6.3	3.4	20 Sep. 1783 – 16 Sep. 1792	9	
II 11	σ Ori	12.7	3.7	8.8	5.1	7 Oct 1779 – 19 Nov. 1781	6	
II 22	ε Per	5.7	2.6	8.9	6.3	2 Aug. 1780 – 30 Oct 1802	10	
II 27	δ Gem	6.5	3.6	8.2	4.6	13 Mar. 81 – 6 Feb. 1804	11	
II 33	β Ori (Rigel)	10.0	0.3	6.7	6.4	1 Oct. 1781 – 11 Jan. 1806	49	T

Table 1-13: Double stars for parallax measurement; bold = objects, later found out by Herschel to be physical pairs. 'Obs' = number of observations. CH: T = mentioned in the 'Temporary index' as 'stars remarkable for use in parallax'.[168]

Of course, Herschel was not successful. His mean positions were not adequate enough to see any changes in the position of the bright ('near') component relative the faint ('far') one. Moreover, in 1803 his continued observations of double stars revealed that John Mitchell was right: there are actually physical pairs in which the components revolve around each other according to Newton's theory of gravitation.[169] Castor, for instance, was shown to have an orbital period of 342 years, which is astonishingly near to the exact value (350).[170] Herschel conceded:[171] "the possibility that two stars, whatsoever be their relative magnitudes may revolve, either in circles or ellipses, round their common center of gravity." He used the term 'binary stars', among them even both pairs in the celebrated 'double-double' ε Lyr.

1.6. Red and variable stars

1.6.1. Herschel's 'garnet stars'

The fourth magnitude star μ Cep (Erakis), commonly known as Herschel's Garnet Star, is probably the most prominent red star. The

standard reference is Herschel's paper 'On the Proper Motion of the Sun and Solar System', published in 1783.[172] Therein a section features 'Stars newly come to be visible'. Nine objects are listed; the third is the famous red star:

A very considerable star, not marked by Flamsteed, will be found near the head of Cepheus. Its right ascension in time is about 2' 19" preceding Flamsteed's 10th Cephei, and it is about 2° 20' 3" more south than the same star. It is of a very fine deep garnet colour such as the periodical star o Ceti [Mira] was formerly, and a most beautiful object, especially if we look for some time at a white star before we turn our telescope to it, such as α Cephei, which is near at hand [4° northwest].

A discovery date is not given, but we find it in *Journal No. 4*, covering a period of the third star review (Figure 1-27). On 27 September 1782, Herschel wrote:[173] "A very considerable star not marked in Fl. Atlas [Coelestis], its place should be there about 45' past 21^{h}, 32½ Deg Polar distance, it is of a very deep fine garnet. This must be looked up often, very beautiful indeed."

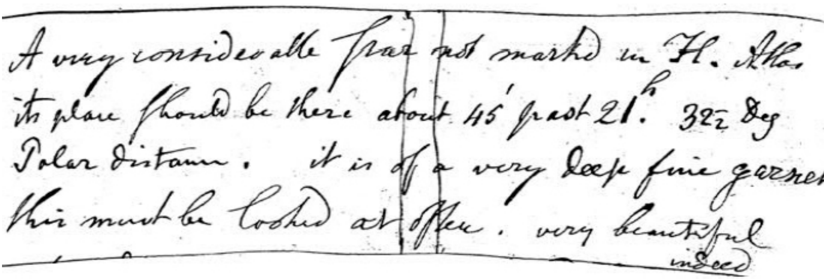

A very considerable ſtar not marked in Fl. Atlas
its place ſhould be there about 45' past 21h. 32½ Deg
Polar distance. it is of a very deep fine garnet
this must be looked at often. very beautiful
indeed

Figure 1-27: Discovery record of Herschel's Garnet Star in Cepheus (from *Journal No. 4*).

In that September night, Herschel found seven double stars. All are in Cepheus and four of them (I 49, III 71, III 72, IV 79) are near μ Cep, located in the southern part of the constellation. At first, he gave a wrong position for his red star (Figure 1-28). Herschel re-visited the area on 16 March 1783: "New Garnet Star Cephei, uncommonly beautiful, 460. With 932 finely distinct, seems of a larger diameter than the stars of that size in the finder generally are. With 1504 very well defined. The diameter is not larger than

that of 10 Cephei with the same power. The colour continues the same with all the powers, with the naked eye rather larger than the 9th Cephei."

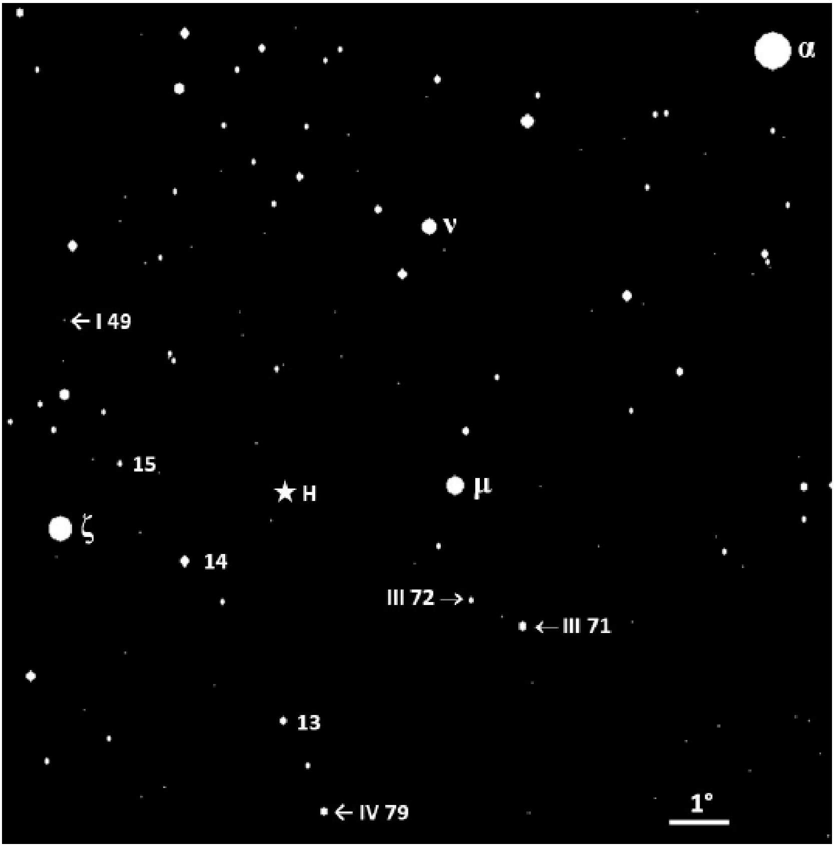


Figure 1-28: The vicinity of Herschel's Garnet Star μ Cep. His wrong position is marked by the 'star H'. Four double stars are labelled.[174]

On 24 March 1783, Herschel observed the double stars III 71 and III 72, located 1.3° southwest of μ Cep. Another observation followed on 5 April 1783: "Garnet Star Cephei. With the 20ft reflector is a most beautiful object; the colour being very vivid & the same as before described. There are great many stars about it."

On 21 May 1783, the red star was the target of a 'prismatic experiment' at the 10-ft reflector. Herschel used a prism at the eye-piece and described the colours, seen in the continuous spectrum.

Of course, the red part of the spectrum dominates: "The spectrum of α Cephei with 10ft reflector power about 100 gave the colours r o y g b p v [red, orange, yellow, green, blue, purple, violet]. The Garnet Star gave only r y g perhaps o may be there in some small degree. I repeated the experiment several times on both stars but could find no b p v in the Garnet Star."

On 29 September 1783, Herschel showed the red star to his friends Alexander Aubert and Charles Blagden, using the 7-ft and the small 20-ft.[175] The object appears twice in the sweep campaign. In sweep 768 (16 October 1787) we read: "7 m. of a deep orrange [sic] colour, or pale garnet. Very different from all the stars in this neighbourhood. U794". Because the star was not in the *British Catalogue*, it was entered as no. 794 in Caroline's list of 'unknown stars'.[176] The record of sweep 875 (1 November 1788) gives: "6 m. garnet colour. U794". It is interesting that Herschel does not mention his earlier observations. It seems that he was not prepared to encounter the star. Table 1-14 lists Herschel's eight observations of the red star in Cepheus, covering a period of six years.

Date	Source (RAS)	Telescope	Remarks
27 Sep. 1782	W.4/1.3: 238	7-ft	'very deep fine garnet'
16 Mar. 1783	W.4/1.4: 349	7-ft	'New Garnet Star Cephei'
24 Mar. 1783	W.4/1.4: 351	7-ft	double stars near Garnet Star (III 71, III 72)
5 Apr. 1783	W.4/1.4: 363	small 20-ft	'Garnet Star Cephei'
21 May 1783	W.4/1.4: 385	10-ft	'prismatic experiment'
29 Sep. 1783	W.4/1.5: 443	7-ft, small 20-ft	visitors: Alexander Aubert, Charles Blagden
16 Oct. 1787	W.2/3.7	20-ft	sweep 768, U794
1 Nov. 1788	W.2/3.7	20-ft	sweep 875, U794

Table 1-14: All observations of Herschel's Garnet Star μ Cep.

In Herschel's 1783 paper, we read that μ Cep "is of a very fine deep garnet colour such as the periodical star o Ceti [Mira] was formerly." This indicates that it was not his first red star. Indeed, a study of the documents reveals eight cases. For this task, Caroline's 'Temporary Index' was helpful; it contains a list of 'Coloured Stars'.[177]

The colour of the variable star Mira (located in 'Collo Ceti') was first mentioned on 8 September 1780: "The colour was very remarkable being darker red (or rather garnet colour) than any I remember to have seen before among the fixt stars." There are five

more observations, mentioning the colour: ‘garnet’ (22 October 1781), ‘fine garnet’ (21 August 1783), ‘garnet but not deep’ (sweep 280, 20 September 1784[178]), ‘deep garnet colour’ (2 December 1790). Probably, the redness of Mira was perceived by earlier observers, but there is no record.[179] It was seen as a double star (IV 1) on 19 October 1779, the pair is, however, only optical.

A most interesting observation was made on 18 November 1781, which was in fact Herschel's first discovery of a red star. He saw the object shortly after “5h in the evening” and noted rather cryptic in *Journal No. 3*: “the trefoil is north following k & colour reddish”.[180] Fortunately, *Fixt Stars No. 2* is more detailed: “star in the trefoil near k Aquilae. The trefoil is north following, colour inclining to red. Too low for other observations and the colour not to be trusted to.”[181] What is the “trefoil near k Aquilae” and which “reddish star” is meant? The star 9 Aql (now η Sct) is called k in the *British Catalogue*; it is labelled with this letter in the *Atlas Coelestis*. Herschel used the term ‘trefoil’ for a triangle of stars with comparable magnitudes. The triangle north following k is framed by 12 (i), 14 (g) and 16 (λ) Aql; a fourth star, 15 (h), lies between 14 and 16 (Figure 1-29).

Is there a red star in or near this pattern? Indeed, and a very remarkable one: V Aql, one of the reddest stars in the sky.[182] No doubt Herschel saw this stunning object, though the observation was difficult. At 5:30 pm the southern part of Aquila was about to set (“too low for other observations”); the red star was only 15° above the horizon. The star was his second object of two in the observing session. The first was 17 Dra, the double star I 4 (found on 8 August 1780). Thus, starting at 5 pm, Herschel turned the 7-ft reflector from Draco to southern Aquila, 66° across the sky. Alas, he never visited the red star again.

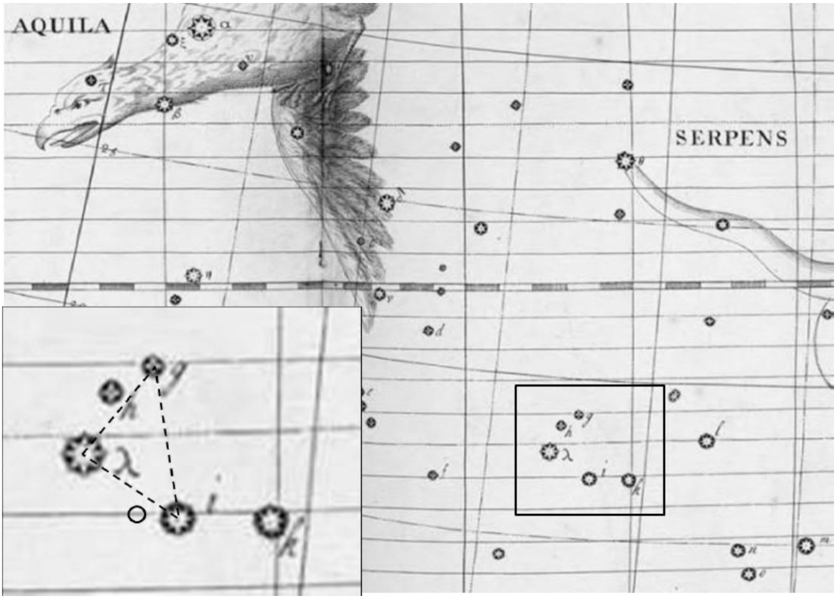


Figure 1-29: Chart showing the discovery situation of the red star V Aql (marked by the small circle; see text).

In the literature, the discovery of V Aql is credited to Julius Schmidt (1872). However, Bessel had previously measured the star in 1823 during his zone observations at Königsberg.183 Herschel's observation is mentioned in Caroline's 'Temporary index' under the heading 'Low situations not proper observing the colours of stars'. No doubt at a higher altitude, he would have applied the term 'deep garnet' for this very red object in Aquila.

Star	V	B-V	Date	R	Ref (RAS)	Description	Remarks
o Ceti	6.5	1.1	8 Sep. 1780	2	W.4/1.1: 74	rather garnet; garnet but not deep	Mira
V Aql	6.9	4.3	18 Nov. 1781	2	W.2/1.3: 40	deep orange	Bessel 1823, Schmidt 1872
RT Cnc	7.6	1.2	20 Jan. 1782	2	W.4/1.2: 181	garnet	
γ CMi	4.3	1.4	30 Jan. 1782	2	W.4/1.2: 181	fine garnet	
6 Aur	6.5	2.7	5 Mar. 1782	2	W.4/1.2: 196	garnet	Birmingham 1876
μ Cep	4.0	2.4	27 Sep. 1782	2	W.4/1.2: 238	very deep fine garnet; garnet colour	Herschel's Garnet Star
5 Lac	4.4	1.7	4 Oct. 1782	2	W.4/1.3: 247	fine garnet	Birmingham 1876; V412 Lac
119 Tau	4.3	2.1	28 Dec. 1782	3	W.4/1.3: 288	garnet	Lalande 1797, CE Tau
X Cnc	6.4	2.1	31 Dec. 1782	3	W.4/1.4: 295	garnet	J. Herschel 1832

Table 1-15: Herschel's 'garnet stars', found in the star reviews (R). Except γ CMi and 5 Lac all are variable. V = visual magnitude (maximum); B-V = colour index (larger value means redder).184

Table 1-15 lists eight strongly coloured stars, found in the star

reviews (most of them are called ‘garnet’). Though the stars were already known (except V Aql), Herschel was the first to detect their remarkable colour. The sweeps brought another 16 stars, among them are prominent ones like Hind’s Crimson Star, Secchi’s La Superba or S Cep with an extreme colour index of B-V = 4.7 mag (see Table 2-11).

1.6.2. Observing ‘periodical stars’

Other targets were variable stars. Herschel’s favourite was Mira (ο Cet), located in ‘Collo Ceti’ (neck of the whale).[185] Due to a minimum phase, he was not successful when viewing with naked eye on 20 October 1777: “I looked out for the periodical star in Collo Ceti; but it was not visible, if its period is 312 days, and is not visible now, it should be so about Christmas.” But on 18 December, he wrote about the ‘miraculous’ star: “I saw the periodical star in Collo Ceti; about a fortnight ago I began to expect it as there was I believe some faint appearance of it then, it is now about the size of ζ [Cet] but not as large as δ.” He looked again on 26 January 1778, finding the star “larger than δ but less then ν”. Many observations would follow until 1810.[186] They also showed Mira as a red star and as a (supposed) double star.[187]

Herschel knew about variable stars from the chapter ‘Of new periodical stars’ in Ferguson’s *Astronomy*.[188] Nine cases are mentioned in the book. We now know that three of them are due to transient phenomena: the supernovae watched by Tycho Brahe in Cassiopeia and Johannes Kepler in Ophiuchus and Hevelius’ Nova in Vulpecula.

Ferguson’s nine ‘periodical stars’ are:

- ‘new star’ in Cassiopeia, discovered by Cornelius Gemma in 1572 [Tycho’s supernova]
- ‘Stella Mira, or wonderful star, in the neck of the Whale’, seen by David Fabricius 1596 [ο Cet]
- ‘changeable star in the neck of the Swan’, found by Willem Blaeu in 1600 [P Cyg]
- ‘new star near the heal of the right foot of Serpentarius’ of 1604, seen by Johannes Kepler [Kepler’s supernova]

- ‘new star’ of Johannes Hevelius, appearing in 1670 [Nova Vulpeculae]
- ‘new star’ found by Gottfried Kirch in 1686, “which returns periodically in 404 days” [ε Cyg]
- ‘star in the neck of the Bull’, seen by Giovanni Domenico Cassini in 1672, but ‘not visible in Tycho’s time; nor when Bayer made his figures’ [not identified]

Table 1-16 lists Herschel’s observations of 15 variable stars.[189] Seven cases were found by him; the rest is due to earlier observers. Polaris is interesting: after he found it to be double on 24 August 1779, he later noticed a slight variability (based on observations made 1783–98).[190]

Star	Observing period	Name	Remarks
o Cet	20 Oct. 1777 – 30 Oct. 1810	Mira	Fabricius 1596
β Lyr	12 May 1782 – 21 Sep. 1796		Goodricke 1784
β Per	27 Apr. 1783 – 8 Oct. 1804	Algol	Montanari 1669
α Her	12 May 1783 - 25 Sep. 1810	Ras Algethi	
β Her	12 May 1783 – 26 May 1797		
ζ Her	12 May 1783 – 30 Apr. 1797		
π Her	12 May 1783 – 21 Sep. 1796		
α UMi	18 Aug. 1783 – 30 Dec. 1798	Polaris	
η Aql	8 Feb. 1785 – 21 Sep. 1797		Pigott 1784
δ Cep	29 Jul. 1785 – 19 Apr. 1798		Goodricke 1784
34 Cyg	15 Sep. 1792 – 30 Dec. 1795	P Cyg	Blaeu 1600
R Leo	14 Feb. 1795 – 1 Feb. 1796	Mayer 420	
χ Cyg	26 Oct. 1795 – 30 Dec. 1795	(‘garnet star’)	Kirch 1686; Figure 2-68
R Sct	25 Oct. 1796 – 3 Nov. 1796	Pigott’s variable	Pigott 1795
R CrB	25 Oct. 1796 – 25 Oct. 1796	Pigott’s variable	Pigott 1795

Table 1-16: Herschel’s variable star observations. Seven cases were found by him (bold).[191]

Herschel had various explanations about ‘periodical stars’, like changes in the luminous atmosphere (‘sunspots’) of an inherently dark object or an in-/decrease of the brightness due to a periodical motion of the star in the line of sight (being nearer and farer).

1.7. Messier objects

Occasionally, Herschel viewed known clusters and nebulae in the

star reviews with various instruments, ranging from a small achromatic refractor to reflectors of 7-, 10- and 20 feet focal length with apertures of 4 to 12 inches. This section mainly covers Herschel's early observations of Messier objects, made between 1 March 1774 and 28 October 1783, when the sweep campaign with the 18.7-inch reflector started.

The first observations of nebulae were focused on objects plotted on the Harris maps (see Table 1-1). These are mainly Messier objects. However, this designation was not known to Herschel at that time, though the first *Messier Catalogue* had already appeared in 1774. They are located in Scutum (M 11), Hercules (M 13), Andromeda (M 31) and Orion (M 42). The Orion Nebula was Herschel's livelong favourite. 12 observations are recorded until 6 August 1780 (see below) and a further 19 until 28 October 1783; most of them were made with the 7-ft.

On 22 August 1779, shortly after starting the second review, Herschel saw a "Nebula without stars in it" in Hercules, using a "7ft Reflector, power 222, aperture 4 inch".[192] This is the globular cluster M 13, seen again on the 29th: "between η and ζ [Her] is a nebula but there is no star in it". Five observations are recorded until 28 October 1783.

On 12 September 1779, Herschel inspected the stars i, k and ℓ in 'Scutum sobies.' (12 Aql, η and β Sct). Then he saw a non-stellar object: "Nebula seems to be a prodigious number of small stars surrounded with lustre and glare". This is the bright open cluster M 11 in Scutum, known as the Wild Duck Cluster. It was observed again on 7 August 1780: "Nebula in Scutum Sob. Has a great number of stars but the largest is not (as Mr. Mitchell supposes) near the middle."[193] Five observations are recorded until 28 October 1783. M 11 was never observed in the sweeps.[194]

On 6 August 1780, Herschel wrote in *Journal No.2*:[195] "Andromeda. Nebula has no star in the brightest part", seen with the 7-ft (6.2-inch) at magnification 222. Eight observations of M 31 were made until 28 October 1783 (with the same telescope). Herschel had now seen five Messier objects: M 11, M 13, M 31, M 42 and M 45 (though there is no written report, he had undoubtedly seen the Pleiades from the beginning). Encouraged by his success in nebular

astronomy, he made a plan: “To be observed: all Nebulas, their stars counted, and the form delineated.” Five objects are mentioned: Andromeda Nebula, Aquila Nebula, Sagittarius Nebula, Perseus Nebula and Hercules Nebula. The Orion Nebula is not explicitly mentioned. By ‘Aquila Nebula’ the cluster M 11 in Scutum is meant. The ‘Sagittarius Nebula’ is M 22, plotted on the southern Harris map. By ‘Perseus Nebula’ the Double Cluster is meant.

By the end of 1781, when the second review was finished, Herschel had already observed seven Messier objects: M 8, M 11, M 13, M 31, M 42, M 44 and M 45. Praesepe in Cancer (M 44) was seen on 21 February 1781, noting “ε [Cnc] a constellation”. The Pleiades in Taurus (M 45) were inspected for double stars on 17 August 1779. In all cases, a 7-ft reflector was used. All objects are listed in Messier’s first catalogue, containing M 1–45. Although published in 1774, it was not known to Herschel.[196] From the Harris maps only M 22, the globular cluster in Sagittarius, was missing. This southern object had to wait until 1783. A question remains: How was Herschel able to find the Lagoon Nebula M 8 in Sagittarius? The nebula is mentioned by Ferguson, but a place is lacking and the southern Harris map does not show it. This issue will be treated in the next section.

As already mentioned, William got the second version of the *Messier Catalogue* in December 1781.[197] It contains M 1–68; an appendix gives M 69 and M 70. However, having just started the third review, he paid more attention to double stars. By the turn of the year, Caroline plotted the positions of all Messier objects into the *Atlas Coelestis*. They are marked by a dot, often labelled by an underlined M-number (Figure 1-30).

Figure 1-30: Chart of the *Atlas Coelestis* showing M 31/32 in Andromeda and M 33 in Triangulum, marked by an underlined number and dot (see rectangles); note William's 'Flamsteed numbers', like 43 And (β).

Herschel's low interest in Messier objects in the third review changed in August 1782. In *Journal No. 3* we see two entries on the 29th: "Nebula 52nd of Messiers" and "Nebula 57". M 52 is an open cluster in Cassiopeia ("a group of small stars appearing nebulous with small power"); it was seen again exactly a year later.

Herschel wrote about M 57 in Lyra: "With 227 extremely curious not quite round. The greatest light is at the outside and in the middle it seems to be dark. I suspect the left side at least to consist of very small stars. I shall endeavour to apply the [small] 20ft to it as soon as convenient." A sketch was made. The curious object was

again viewed on 3 May 1783, when another sketch was made.198 Further observations are recorded on 31 May and 29 September. On 9 July 1784, M 57 was first viewed with the 18.7-inchreflector199; a third sketch was made, published in 1785, showing “a perforated nebula, or ring of stars”, which marks the origin of the popular name Ring Nebula.200 Figure 1-31 shows all sketches. Herschel wrote:

The 57th Nebula of the Connoiss. des Temps is an oval with a dark place within, and the nebulosity is partly of the resolvable kind; the northern side contains either a few stars in a row or at least very resolvable light; the southern side of also contains the same. The fainter light of the eastern and western side seems to incline to the resolvable appearance, 240 shewed several small stars near, but none that seem to belong to this curious nebula. It is near 2' in diameter I think; the two vertices of the transverse seem less bright & bot so well defined as the rest.”

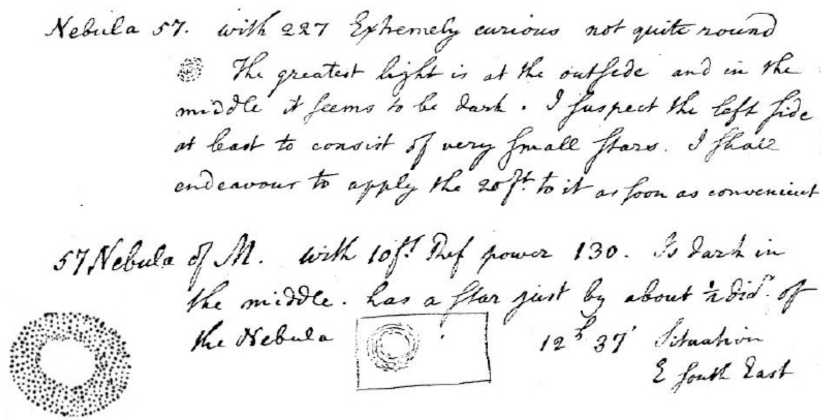


Figure 1-31: Herschel’s observations and sketches of the Ring Nebula M 57 in Lyra. Above: 29 Aug. 1782, below: 3 May 1783, below left: 9 July 1784, published in 1785 as ‘A perforated Nebula, or Ring of Stars’.

The story about Herschel and the (second) *Messier Catalogue* actually began on 5 August 1782, when he encountered a strange object near the star 5 Ser. Using the 7-ft, he saw “Serpens 5th another nebulous”. Piqued by the event, he checked the situation in

the next night: "Near the 5th of Serpens is a nebulous star or telescopic comet. When I looked with 460 the power I had on I could not see it, therefore lowering the power it appeared as I expected to be nebulous or hairy, it is bright in the middle, the coma is about 3' diameter. It appears to be perfectly circular and may possibly be a comet." On 9 August, he wrote: "I took some observations of the nebula or apparent comet. There are some small stars very near it the nearest of these is about 30" or 40. Mons. de Luc observed it with me."[201] Herschel made a sketch. No doubt things would become clearer if any motion or change could be detected; but on the 11th we read: "I can not perceive any change in the situation of the nebula."

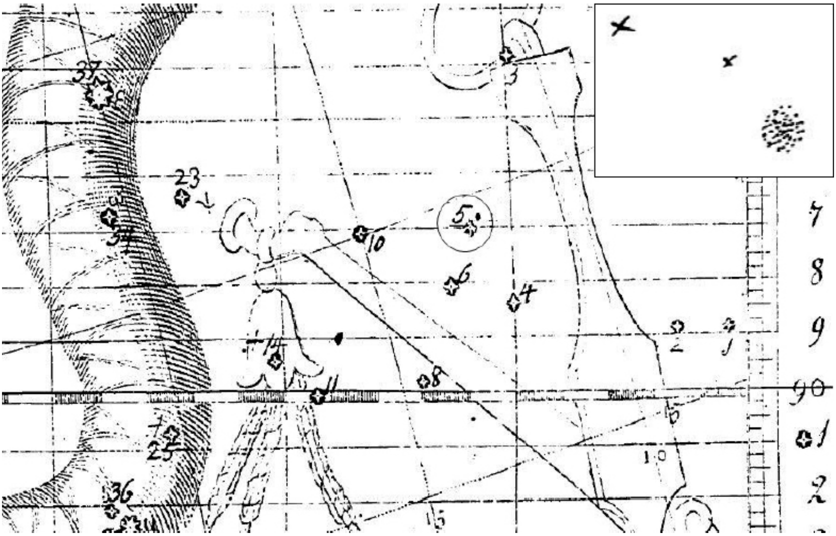


Figure 1-32: Chart of the *Atlas Coelestis* with M 5 marked by Caroline by a dot plus underlined number (see circle). The star 5 Ser, located immediately southeast, was separated by a small separating figure. Inset: William sketch of the 'comet'.

The mystery was eventually solved on 1 September: "On looking over Messiers Catalogue find it among his nebulas No. 5."[202] Herschel had seen no comet, but the globular cluster M 5 in Serpens.[203] However, there was another source to look at, the *Atlas Coelestis*. Caroline had entered all Messier objects up to M 70, marked by a dot (in many cases an underlined number is added;

Figure 1-32).[204] On 1 January 1783, M 5 was looked up again; the 7-ft showed "several stars" in the nebulous object. This was confirmed on 4 March with 460×: "has several very small stars in it. They are however so small I can but just perceive some, and suspect others." These were indications that certain nebulous objects could at least partly be resolved into stars.

Inspired by this success, Herschel felt his way forward in the field of nebular astronomy. From autumn 1782 on, he observed Messier objects in a more systematic manner with his 7-ft (using 227× and 460×), parallel to the third review. And beginning in April 1783, he also observed with the 10-ft and small 20-ft for this purpose. This brought important progress, especially concerning the resolution of a certain kind of nebulae, later termed 'globular clusters' by him.

Let's have a look at the period from autumn 1782 to spring 1783. On 3 September 1782, Herschel tried the open cluster M 26 in Scutum and the globular cluster M 15 in Pegasus. The former was a bit frustrating: "I looked in vain with a compound eye piece for it. There are a great number of small stars in that quarter all over the Via Lactea." Although he met the right place, the field of view (4.5') was too small for the extended star cluster, located in the already overcrowded Milky Way. All went well on 3 March 1783 with the 10-ft at 250×: "A small parcel of stars in the form of a Gothic-Arch; Perhaps 60 or 80 of them." No star was seen in M 15 with the 7-ft, even at 460×. Further observations were made on 31 May and 24 August 1783.

The open cluster M 37 in Auriga was viewed on 29 October. There is no observation in the sweeps. The two other bright Auriga clusters, M 36 and M 38, were already seen on 24 August with the 7-ft. All three build a nice chain ranging over 6° from northwest to southeast.

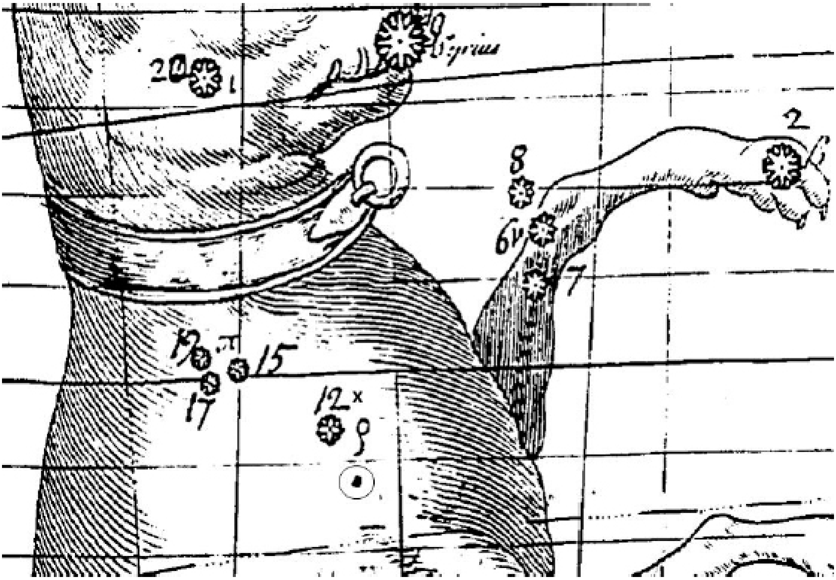


Figure 1-33: Chart of the *Atlas Coelestis* with M 41, marked by Caroline by a dot 45' southwest of ρ CMa (circle). However, the correct place of the bright open cluster (south of 'Syrius'), is 15' northwest (x).

On 4 November, Herschel noted: "Of a cluster of small telescopic stars following β Sagittae the most south & largest, treble 1st class"; the 7-ft was used at 227 ×. This is the coarse globular cluster M 71. Herschel, not knowing about its identity, made an independent discovery (see next section). The object was seen again on 30 May 1783. On 28 December, Herschel wrote: "Near ρ Canis majoris [12 CMa] is a very rich spot. Contains 2 double stars of 4th class." This is the bright open cluster M 41, 15' northwest of the star. Curiously, the second double star catalogue does not contain the two class IV objects. Caroline's place for M 41 in the *Atlas Coelestis*, marked by a dot, is interesting: it lies 45' southwest of ρ CMa. Though, Messier's position for 1765 is correct, Caroline put M 41 at an incorrect place for 1690 (Figure 1-33). She probably was not aware of Messier's using the equinox of the date (see footnote 204).

On 1 January 1783, the small 20-ft reflector was pointed at a non-stellar object for the first time. Of course, it was the Orion Nebula (M 42), looking "remarkably beautiful". Dr Lind joined in the

observation.

The Pleiades (M 45) were viewed with the naked-eye on 9 February 1783, when the Half Moon occulted parts of the large star cluster. Herschel wrote:[205] "I saw the Emersion & Immersion of some of the Pleiades, the latter did not seem to me to be instantaneous, my Sister is booking her observation of it which brings it; to my memory." Indeed, Caroline had watched the event:[206] "Saw 1 star of the Pleiades Em[ersing], and two Im[mersing]; but the wind & clouds would not permit to know what stars they were." M 45 had already been visited 17 August 1779, when searching for double stars.

No new M-object was observed until 26 February 1783.[207] In that night Caroline found the open cluster M 93 in Puppis and William confirmed it (see section 1.9). The night of 4 March brought another discovery when Herschel inspected an area in Lepus. At 227× he saw a "cloudy star [which] appears to be a nebula without stars".[208] He had found the globular cluster M 79 – but was in doubt on March 26: "What I have set down as a Nebula near β Leporis, has probably been a telescopic Comet, for it is no longer to be seen in that place, however the constellation being so low I can not be perfectly sure of its absence." All-clear was given on 28 September with the aid of the 7-ft: "79 Nebula of Mess. is that which I discovered March 4th 83."

What is so special about M 71, M 79 and M 93? All three are not listed in the second *Messier Catalogue*, which ends with M 70.[209] In March 1783, Herschel still did not possess the final catalogue, though it was printed in 1781. Therefore, objects above M 70 were not plotted by Caroline in the *Atlas Coelestis*. Thus M 71, M 79 and M 93 were independent discoveries.

On 27 February 1783, Herschel observed the globular cluster M 53 in Coma Berenices:[210] "with 227 it is all nebulosity. With 460 there is a suspicion of stars. The nebula is an extremely faint object with the latter power." Two other objects of that type followed on 6 March and 2 April: M 3 in Canes Venatici and M 10 in Ophiuchus, respectively. No star was seen in M 3, but M 10 looked better: "I suspect to be stars. 227, pretty certain they are small stars. 460, I am certain they are stars, very close and very small. I see at least a

dozen (by guess) but they are too small to count."

Another highlight was M 1 in Taurus. This was Messier's first deep-sky object, found on 28 August 1758. Later he became aware that it was discovered by the English astronomer John Bevis about 1731.[211] Herschel examined the famous Crab Nebula on 24 March.[212] However, nothing but a starless patch appeared with 227 ×. The object was viewed again on 20 September, now with the small 20-feet at 200 ×: "I suspect it strongly to be stars, but did not expect to resolve it to night for the weather is so windy that every star is indistinct." Herschel knew that this long reflector on its simple pole mounting was sensitive to wind.

On 26 March, William and Caroline saw the open cluster M 67 in Cancer. The 2nd of April was a 'Messier night' with six objects. While M 53 and M 93 saw their second observation, four were new: M 10 (see above), the open cluster M 35 in Gemini and the galaxy pair M 65/66 in Leo, Herschel's second view of a galaxy after M 31.

On 3 April, the small 20-ft was pointed a second time at a non-stellar object (after M 42 on 1 January). It yielded a closer view of the large open cluster M 35 in Gemini. Though not the ideal target for the instrument with its small field of view, Herschel estimated about 400 stars and perceived "no kind of nebulosity mixed with them".

A month later, on 3 May, a 10-ft Gregorian reflector with 9 inches aperture was tested on five Messier objects: M 8, M 9, M 11, M 26 and M 57 (the dark inner region appeared much clearer now). The globular cluster M 9 in Ophiuchus was new. With the 10-ft at 250 ×, Herschel could see "stars in it & make no doubt a higher power & more light would resolve it into stars. This seems to be a good Nebula for a purpose pf establishing the connection between Nebulas in general & stars in clusters." His idea that nebulae are star clusters strengthened.

The globular cluster mission continued in May. On the 5th, Herschel saw M 4 near Antares for the first time: "10ft 180. All resolvable into stars but they are extremely small. 250. Still better I can count a great number of them while others escape the eye by their minuteness." However, the planetary nebula M 27 looked similar:

"A strong suspicion of its consisting of stars." M 4 was tried again the next night, now with the small 20-ft at 250×: "So distinctly resolved into stars that I can count above 50 of them, excluding straggling ones at some distance." A new globular cluster was seen that night with the 7-ft at 227×: M 56 in Lyra: "A suspicion amounting to near a certainty of its being all stars. I see many of them." The object was never observed in the sweeps. Another first observation was of the open cluster M 39 in Cygnus (7-ft).

In later May, Herschel observed four new Messier objects with the 10-ft: M 12, M 19, M 62 and M 71. The first three are globular clusters in Ophiuchus. With 300×, M 12 appeared on the 21st as "A cluster of close stars of very different sizes. All resolved into stars without Nebulosity. The largest star is not in the middle." On the 28th, using a power of 250×, M 19 was "resolved into stars, i.e. I can count 5 or 6; & all the rest of the light appears mottled like other Nebulas when not sufficiently magnified and illuminated to show the stars." Right after, M 62 was observed with the same eye-piece: "A strong suspicion amounting to almost a certainty of its consisting of stars tho' I can distinguish none." Herschel had become an experienced observer of this compressed type of cluster, described by Messier as "nebula without stars". The fourth target, viewed on 30 May, the coarse globular cluster M 71 in Sagitta – first observed on 4 November 1782 but not identified – shows that Herschel now possessed the third *Messier Catalogue* with 103 entries, published in 1781.[213] He noted: "Messiers Nebula 1780". In the catalogue we read: "Nebula discovered by M. Méchain on June 28, 1780." An observation by Messier of 2 October 1780 is also mentioned.

Of the 103 objects listed in the final *Messier Catalogue*, Pierre Méchain discovered 19; the six additional objects M 104–109 must also be credited to him. Messier's score is 41. Third place goes to Hodierna with eight objects. Figure 1-34 portraits of the three deep-sky observers.[214]

In the night of 30 March 1783, Herschel was unable to find "Messiers 1st & 2nd of the eleven nebulas in Virgo; near the 6th Coma." These are the galaxies M 98 and M 99 in Coma Berenices.[215] Caroline plotted the remaining Messier objects (M 71

to M 103) into Herschel's copy of the *Atlas Coelestis*; not all dots show a label (underlined M-number). Due to a remark made by her on 29 July 1793 in the third observing book, there is evidence that she had entered Messier objects in the Harris maps too:[216] "I saw nothing besides the Nebula No. 81 & 82 & 94 and two more which are marked in Harrises map but the number is effaced I must look for the number when there is more time."

Figure 1-34: Main contributors to the *Messier Catalogue*: Charles Messier, Pierre Méchain and Giovanni Hodierna.

Concerning planetary nebulae, Herschel's first objects were M 57 (29 August 1782) and M 27 (30 September 1782), both seen with the 7-ft. Follow-up observations were made that year with the 10-ft and small 20-ft. On September 20, he saw M 27 with the latter at 200 ×, noting: "Appeared faintly mottled, so that I doubt not but it consists of stars." On 24 October, he searched in vain for the planetary nebula M 76 in Perseus with the 7-ft: "fine dark night, could not find it". Indeed the 10.1 mag object is a difficult target.[217] Méchain had discovered the nebula on 5 September 1780 with a 3-inch refractor.

In the three months July, August and September 1783 before starting the sweep campaign in October, the observation of Messier objects got priority against the third star review, though that was in its final phase. In July 1783, Herschel made 18 observations in six nights, mainly using the small 20-ft. 14 new Messier objects were viewed (the 30th and 31st alone brought nine). Among them are eight globular clusters: M 22, M 28, M 54, M 55 in Sagittarius, M 2 in Aquarius, M 14 in Ophiuchus, M 30 in Capricornus and M 92 in

Hercules. M 22, being on Herschel's agenda since 6 August 1780 and one of the few 'nebulae' plotted on the Harris maps, was eventually viewed on 4 July 1783 with the small 20-ft. He resolved the object into stars (the 7-ft did not show it at all). M 22 was seen again three days later. The observation of M 30 with the small 20-ft at 200× once again led Herschel to speculate about the relation between nebulae and clusters: "Plainly resolved into very small stars. It is a difficult step, i.e. if we divide the transition from the Pleiades down to the Nebula in Orion into six steps this is perhaps the 4th towards the real Nebulas."

M 92, "Messiers new Nebula in Hercules",[218] was observed with a "new perpendicular Newtonian sweeper, power 15". The instrument – made for Caroline – had a mirror of 4.2 inches diameter and a focus of 27 inches (magnification 24 gave a field of 2.2°). Herschel noted that M 92 "appears with this power like a cloudy star". Except for M 2, observed with the 7-ft, all others could be resolved. The dense object in Aquarius was tried again on 31 July with the small 20-ft at 200×: "I can count 18 or 20 stars but they are so thickly set one behind another that their light mixed together makes a very strong glare." Six open clusters were observed for the first time: M 6, M 7 in Scorpius, M 16 in Serpens, M 18, M 23 and M 25 in Sagittarius. The observation of M 7 on 30 July, using the sweeper, is exceptional. The open cluster is the Messier object with the lowest declination, about -35°.[219] In that night, it rose only 2° above the horizon! Herschel counted "about 20 stars". M 7 is among the objects mentioned by Ferguson, but not plotted on the southern Harris map. It was never observed in the sweeps.

Herschel was fascinated by viewing such southern objects. In the night, he also searched the constellation Piscis Austrinus for double stars with the small 20-ft (200×). Near ε PsA, only 10° above the horizon, he thought he found one: "I can not verify the stars being double tho' I have still some suspicion. The prismatic power of the Atmosphere [refraction] is a great hinderance; I wish myself at the cape of good hope & view it there."[220] On the 31st, Herschel had his first view of M 17 (Lagoon Nebula) in Sagittarius, using the small 20-ft at 200×: "A very singular Nebula; it seems to be a link to join the Nebula in Orion to others for this is not without possibility of being stars."

The harvest of August 1783 was even better: in seven nights, 27 objects were observed. Herschel used the small 20-ft, the 7-ft and the sweeper. On the 2nd we have Herschel's personal 'Messier-Marathon'.[221] 18 Messier objects were observed in that night. Altogether 12, viewed in August, were new to Herschel: the six open clusters M 21 (Sagittarius), M 29 (Cygnus), M 34 (Perseus), M 36 and M 38 (Auriga) and M 103 (Cassiopeia); the four galaxies M 32 (Andromeda), M 33 (Triangulum), M 81/82 (Ursa Major), the Sagittarius Star Cloud M 24 and the emission nebula M 20 (both in Sagittarius). M 24 was observed with the small 20-ft at 200 ×, which is not appropriate for this large region of stars in the Milky Way ("pretty considerable stars"); Messier gives an extension of 1.5°.[222] The open cluster M 29 in Cygnus was viewed with Caroline's sweeper. M 33, known as the Triangulum Nebula, was seen on 2 August: "Scattered stars with a whitishness too faint to be resolved by this telescope. 7ft compound [eye-]piece."[223] It is interesting that Herschel saw "scattered stars", because in later observations he speaks about a cluster with nebulosity. Messier never mentioned a 'cluster'. On 24 August, Herschel wrote: "A suspicion of extensively small stars; has a nebulous appearance with this low power & vanishes for want of light I put on 278 & 460. The 20 feet will probably resolve it into stars."

Herschel's observation of the galaxy pair M 81 and M 82 in Ursa Major is interesting. Due to its discoverer, the Berlin astronomer Johann Elert Bode, the duo is called Bode's Nebulae.[224] About M 81 we read: "Seems to consist of 4 or 5 stars crowded together with many small ones about them; but I am not satisfied that this is really the case." And for M 82: "I see 5 or 6 stars within the Nebula extended in a row; but weather the light which is also extended consist of stars or nebulosity such as in Orions sword handle [M 42] I can not resolve. Nor do I see the stars in it distinctly tho' I do not doubt them." Both galaxies, forming a wide pair in the north-western part of Ursa Major, were observed with the small 20-ft at 200 ×. This ambiguous result forced Herschel to give a longer comment on an experiment in Aquila, made right after the M 81/82 observation:[225]

Relating to the appearance of nebulae without stars, I tried some excessively small stars near ν Aquila; when ν was perfectly distinct

& round the extremely small stars were dusky or not perfectly defined; (these stars I have often found in my 20ft reflector appear defined & without that duskiness; which difference I ascribe to want of light in one case and a sufficiency in the other to make an impression of a round point.) The excessively small stars were still less defined; and as there are in this neighbourhood stars of all sizes, I saw some so very small that they only gave the idea of a small dusky spot, approaching to a nebulous appearance. By very long attention I perceived small dusky nebulous spots which without such attention might be in view without the least suspicion.

September 1783 brought 21 observations in seven nights (eight on the 20th). Six new objects were seen: the galaxies M 51 (Canes Venatici), M 74 (Pisces), M 77 (Cetus) and M 101 (Ursa Major), the globular cluster M 72 and the nearby star group M 73 (both in Aquarius, see Figure 2-78). The letter is only 1.8° southwest of Herschel's first planetary nebula, NGC 7009.

The 17th brought Herschel's first view of M 51, later called the Whirlpool Nebula[226]: "7 feet 57. Two Nebulas joined together; Both suspected of being stars. Of the most north I have hardly any doubt. 7ft 150. A strong suspicion next to a certainty of their being stars. I make no doubt the 20ft will resolve them clearly as they want light & prevent my suing a higher power with this Instrument. Mr Messier saw them as one only." Herschel clearly noticed the companion NGC 5195 – an independent discovery (see next section). Méchain had found the object on 31 March 1781, which was unknown to Herschel.[227] An observation with the small 20-ft (200 ×) followed on the 20th under unfavourable conditions: "Most difficult to resolve; yet I do no longer doubt. In the southern Nebula I saw several stars by various glimpses; in the northern also three or 4 in the thickest part of it: but never very distinctly. Evening very bad."

The atmospheric condition is described by two factors: 'seeing' and 'transparency'.[228] The former refers to the steadiness of the air. Turbulent flows (often due to heat or wind) cause erratic variations of brightness, position and colour. This is known as scintillation, best seen on bright stars at low altitude. In the telescope we experience a loss of image sharpness. Poor seeing causes nebulae to

appear blurred or even become invisible. Transparency depends on the amount of air/light pollution and humidity. It effects the sky darkness, which can vary widely. Lower transparency leads to a reduced contrast in the eye-piece. Faint objects can be seen best at maximum sky darkness.

The Pinwheel Galaxy M 101 was also seen twice (same dates as M 51); first with the 4.2-in sweeper, then with the small 20-ft. Herschel finally wrote: “This & the 51st are both so far removed from the appearance of stars that it is the next step to not being able to resolve them. My new 20ft will probably render it easy.” This is an indication that the ‘large 20-foot’ reflector was already under construction; it would be the standard instrument in the upcoming sweep campaign. The poor seeing brought no remarkable results on M 74, M 77, M 1 and M 27 (both revisited). On 20 September, Herschel also saw the reflection nebula M 78: “2 stars (or perhaps crowds of stars for they are not defined) with nebulosity about them.”

M 72 and M 73 in Aquarius were looked-up in vain on 25 September, but were found three days later with the 10-ft. The latter is only a group of four stars (“consists of a few stars arranged in a triangular form”). A bit curious is Herschel’s note on Praesepe (M 44) on the 27th: “A cluster of stars. Mr Wilson found it a little preceding δ Cancri. Day light too strong to examine it.”[229] Undoubtedly, Herschel had already noticed the star cluster on the Harris map and he had indeed seen it on 21 February 1781. However, it is not surprising that he sometimes does not remember earlier observations – the amount of data was simply too large. Of course, Caroline’s various records and tables helped to keep track.

On 23 October 1783, Herschel wrote: “I tried the new Newtonian 20-ft reflector aperture 18.7 inches; it shewed a great number of small stars.”[230] On the 26th, the new instrument got its first real target, the globular cluster M 30 in Capricornus, viewed at magnification 120. Herschel noted: “I can distinctly count 10 stars; the Nebulosity also where it is most compact is mottled and undoubtedly consists of stars.” A sketch was made (Figure 1-35). In the following night, he started his epochal sweep campaign to find new nebulae with the new reflector. Success came immediately,

finding the 10.4 mag galaxy NGC 7184 in Aquarius.

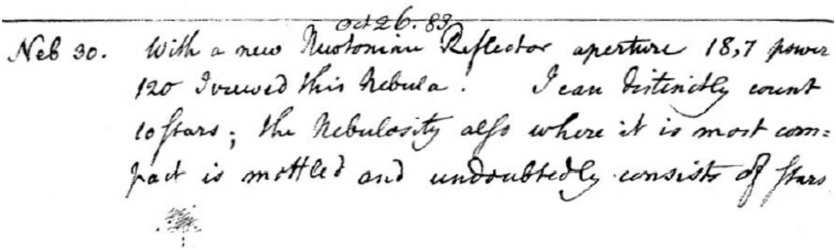

Oct 26. 83
Neb 30. With a new Newtonian Reflector aperture 18,7 power 120 I viewed this Nebula. I can distinctly count 10 ſtars; the Nebulosity alſo where it is most com: pact is mottled and undoubtedly consists of ſtars

Figure 1-35: The first observation with the new 20-ft reflector. The target was the globular cluster M 30 in Capricornus.

M	Date	Ob	Telescope	Con	V	Type	Discoverer	Remarks
42	1 Mar. 1774	24	5.5-ft, 7-ft, s20-ft	Ori	4.0	EN	Peiresc 1610	Orion Nebula, four sketches
45	17 Aug. 1779	2	7-ft	Tau	1.6	OC		Pleiades; second view 9 Feb. 1783 (occultation by the Moon)
13	22 Aug. 1779	6	7-ft (4-in), 7-ft, SS	Her	5.8	GC	Halley 1714	
11	12 Sep. 1779	6	7-ft, 10-ft	Sct	5.8	OC	Kirch 1681	Wild Duck Cluster
31	6 Aug. 1780	7	7-ft	And	3.4	Gx	As-Sufi 964	Andromeda Nebula
8	24 Aug. 1780	3	7-ft, 10-ft, s20-ft	Sgr	5.8	EN	Hodierna 1654	Lagoon Nebula
47	15 Feb. 1781	2	7-ft	Pup	4.4	OC	Hodierna 1654	2nd *Messier Catalogue*
44	21 Feb. 1781	2	7-ft	Cnc	3.1	OC	Aratos 260 B.C.	Praesepe
5	4 Aug. 1782	7	7-ft, 10-ft	Ser	5.7	GC	Kirch 1702	sketch 9 Aug. 1782 (7)
52	29 Aug. 1782	2	7-ft	Cas	6.9	OC	Messier 1774	
57	29 Aug. 1782	4	7-ft, 10-ft, s20-ft	Lyr	8.8	PN	Messier 1779	Ring Nebula, sketch 29 Aug. 1782, 3 May 1783
15	3 Sep. 1782	3	7-ft, s20-ft	Peg	6.3	GC	Maraldi 1746	
26	3 Sep. 1782	2	7-ft,10-ft	Sgr	8.0	OC	Messier 1764	
27	30 Sep. 1782	4	7-ft,10-ft, s20-ft	Vul	7.4	PN	Messier 1764	Dumbbell Nebula
37	29 Oct. 1782	5	7-ft	Aur	5.6	OC	Hodierna 1654	
71	4 Nov. 1782	2	7-ft, 10-ft	Sge	8.4	GC	de Chéseaux 1745	
41	28 Dec. 1782	1	7-ft	CMa	4.5	OC	Aristoteles 325 B.C.	
93	26 Feb. 1783	4	3.5-ft, 7-ft	Pup	6.2	OC	Messier 1781	
53	27 Feb. 1783	3	7-ft, 10-ft	Com	7.7	GC	Bode 1775	
79	4 Mar. 1783	2	7-ft	Lep	7.7	GC	Méchain 1780	
3	6 Mar. 1783	1	7-ft	CVn	6.3	GC	Messier 1764	
48	8 Mar. 1783	1	7-ft	Hya	5.8	OC	Messier 1771	
1	24 Mar. 1783	2	7-ft, s20-ft	Tau	8.4	EN	Bevis 1731	Crab Nebula

M	Date	Ob	Telescope	Con	V	Type	Discoverer	Remarks
67	26 Mar. 1783	2	7-ft, s20-ft	Cnc	6.9	OC	Koehler 1779	
10	2 Apr. 1783	2	7-ft, 10-ft	Oph	6.6	GC	Messier 1764	
35	2 Apr. 1783	2	7-ft, s 20-ft	Gem	5.1	OC	de Chéseaux 1745	
65	2 Apr. 1783	2	7-ft, s20-ft	Leo	9.3	Gx	Messier 1780	
66	2 Apr. 1783	2	7-ft, s20-ft	Leo	8.9	Gx	Messier 1780	
46	3 Apr. 1783	1	s20-ft	Pup	6.1	OC	Messier 1771	
9	3 May 1783	1	10-ft	Oph	7.8	GC	Messier 1764	
4	5 May 1783	2	10-ft, s20-ft	Sco	5.4	GC	de Chéseaux 1745	
39	6 May 1783	1	7-ft	Cyg	4.6	OC	Messier 1764	
56	6 May 1783	2	7-ft	Lyr	8.4	GC	Messier 1779	
12	21 May 1783	1	10-ft	Oph	6.1	GC	Messier 1764	
19	28 May 1783	1	10-ft	Oph	6.8	GC	Messier 1764	
62	28 May 1783	2	10-ft	Oph	6.4	GC	Messier 1771	
22	4 Jul. 1783	2	7-ft, s20-ft	Sgr	5.2	GC	Ihle 1665	
28	4 Jul. 1783	2	7-ft, s20-ft	Sgr	6.9	GC	Messier 1764	
92	6 Jul. 1783	3	7-ft, s20-ft, SS	Her	6.5	GC	Bode 1777	3rd *Messier Catalogue*
23	7 Jul. 1783	2	7-ft	Sgr	5.5	OC	Messier 1764	
14	23 Jul. 1783	2	7-ft, s20-ft	Oph	7.6	GC	Messier 1764	
2	30 Jul. 1783	2	7-ft, s20-ft, SS	Aqr	6.6	GC	Maraldi 1746	
6	30 Jul. 1783	1	s20-ft	Sco	4.2	OC	Hodierna 1654	Butterfly Cluster
7	30 Jul. 1783	1	SS	Sco	3.3	OC	Ptolemy 130	Ptolemy's Cluster
16	30 Jul. 1783	1	s20-ft	Ser	6.0	OC	de Chéseaux 1745	
25	30 Jul. 1783	2	s20-ft	Sgr	4.6	OC	de Chéseaux 1745	
54	30 Jul. 1783	2	s20-ft	Sgr	7.7	GC	Messier 1778	
55	30 Jul. 1783	1	s20-ft	Sgr	6.3	GC	Lacaille 1751	
17	31 Jul. 1783	2	s20-ft	Sgr	6.0	EN+OC	de Chéseaux 1745	Omega Nebula
18	31 Jul. 1783	1	s20-ft	Sgr	6.9	OC	Messier 1764	
30	31 Jul. 1783	5	10-ft, s20-ft	Cap	6.9	GC	Messier 1764	sketch 26 Oct. 1783
20	2 Aug. 1783	1	s20-ft	Sgr	8.5	EN+OC	Messier 1764	Trifid Nebula
21	2 Aug. 1783	1	s20-ft	Sgr	5.9	OC	Messier 1764	
24	2 Aug. 1783	1	s20-ft	Sgr	4.6		Messier 1764	Sagittarius Star Cloud
29	2 Aug. 1783	2	7-ft, SS	Cyg	6.6	OC	Messier 1764	
32	2 Aug. 1783	1	7-ft	And	8.1	Gx	Le Gentil 1749	
33	2 Aug. 1783	2	7-ft	Tri	5.7	Gx	Hodierna 1654	Triangulum Nebula
34	2 Aug. 1783	1	7-ft	Per	5.2	OC	Hodierna 1654	
81	6 Aug. 1783	1	s20-ft	UMa	6.9	Gx	Bode 1774	Bode's Nebulae
82	6 Aug. 1783	1	s20-ft	UMa	8.4	Gx	Bode 1774	Bode's Nebulae
76	8 Aug. 1783	2	7-ft	Per	10.1	PN	Méchain 1780	Little Dumbbell
97	8 Aug. 1783	1	7-ft	UMa	9.9	PN	Méchain 1781	Owl Nebula
101	8 Aug. 1783	3	7-ft, s20-ft	UMa	7.9	Gx	Méchain 1781	
103	8 Aug. 1783	2	7-ft	Cas	7.4	OC	Méchain 1781	
36	24 Aug. 1783	1	7-ft	Aur	6.0	OC	Hodierna 1654	
38	24 Aug. 1783	1	7-ft	Aur	6.4	OC	Hodierna 1654	
51	17 Sep. 1783	2	7-ft, s20-ft	CVn	8.4	Gx	Messier 1773	Whirlpool Nebula
43	20 Sep. 1783	1	s20-ft	Ori	6.8	EN	Mairan 1731	
74	20 Sep. 1783	1	s20-ft	Psc	9.4	Gx	Méchain 1780	
77	20 Sep. 1783	1	7-ft, s20-ft	Cet	8.9	Gx	Méchain 1780	
78	20 Sep. 1783	1	s20-ft	Ori	8.0	RN	Méchain 1780	
72	25 Sep. 1783	2	10-ft	Aqr	9.2	GC	Méchain 1780	
73	25 Sep. 1783	2	10-ft	Aqr	8.9	4 stars	Messier 1780	

Table 1-17: Messier objects, observed from 1 March 1774 to 26 October 1783 with various telescopes (s20-ft = small 20-ft, SS = small sweeper). Bold = object known to Herschel (Smith, Ferguson, Harris maps). Herschel received the second *Messier Catalogue* in December 1781 and the third (final) in May 1783.[231]

From 1 March 1774 to 26 October 1783, Herschel observed 73 Messier objects in 82 nights. 176 observations of the catalogued nebulae and star clusters were made with various telescopes (Table

1-17).[232] However, that left 30 Messier objects yet to be seen, among them the open cluster M 50 in Monoceros, mentioned by Ferguson, but not plotted on the Harris maps. Messier objects remained exclusive targets over many years and Herschel eventually completed the list of all 103, with only one exception: M 40, which is only a pair of faint stars.

In April 1784, Herschel finished his first paper on the 'construction of the heavens' (see section 4.1.1). A part of it concerns observations of Messier objects.[233] He begins: "The excellent collection of nebulae and clusters of stars which has lately been given in the *Connoissance des Temps* for 1783 and 1784, leads me to a subject which, indeed, must open a new window of the heavens."[234] This refers to Messier's second and third (final) catalogues, published in 1780 and 1781, respectively. Herschel tells us: "As soon as the first of these volumes came to my hands, I applied my former 20-feet reflector of 12 inches aperture to them". This is incorrect. He received the catalogue in December 1781, but started his Messier observations on 29 August 1782 with the 7-ft reflector (M 52, M 57). Moreover, the small 20-ft was first used for this purpose on 3 April 1783 (M 35). Herschel continued that he

saw, with the greatest pleasure, that most of the nebulae, which I had an opportunity of examining in proper situations, yielded to the force of my light and power, and were resolved into stars. For instance, the 2d, 5, 9, 10, 12, 13, 14, 15, 16, 19, 22, 24, 28, 30, 31, 37, 51, 52, 53, 55, 56, 62, 65, 66, 67, 71, 72, 74, 92, all which are said to be nebulae without stars, have either plainly appeared to be nothing but stars, or at least to contain stars, and to shew every other indication of consisting of them entirely. I have examined them with a careful scrutiny of various powers and light, and generally in the meridian.

Herschel was proud that his telescopes were superior to that of Messier (3.5-inch refractor). The French astronomer could resolve only obvious cases, like star clusters, but was unsuccessful for globular clusters ("nebulae without stars"). No doubt as a distinguished telescope maker, Herschel wanted a competition – and Messier's objects were ideal targets. It is interesting that 19 of the 29 cases mentioned in the paper are globular clusters; the rest

are galaxies (M 31, M 51, M 65, M 66, M 74) and star clusters (M 16, M 24, M 37, M 52, M 67). The latter type was clearly seen: "I should mention, that five are called clusters of stars containing nebulosity; but my instrument resolving also that portion of them which is called nebulous into stars of a much smaller size, I have placed them into the above number." However, there are still other objects:

To these may be added the 1st, 3d, 27, 33, 57, 79, 81, 82, 101, which in my 7, 10 and [small] 20-feet reflectors showed a mottled kind of nebulosity, which I shall call resolvable; so that I expect my present telescope [20-ft] will, perhaps, render the stars visible of which I suppose them to be composed. Here I might point out many precautions necessary to be taken with the very best instruments, in order to succeed in the resolution of the most difficult of them; but reserving this at present too extensive subject for a future opportunity, I proceed to speak of the effects of my last instrument with regard to nebulae.

M 1 is a supernova remnant, M 27 and M 57 are planetary nebulae, M 33, M 81, M 82 and M 101 are galaxies – types that cannot be resolved. However, it is interesting that Herschel perceived a "mottled kind of nebulosity". The globular clusters M 3 and M 79 were only observed with the 7-ft in that period. Both were resolved in the sweeps with the 18.7-inch reflector.

1.8. William's new nebulae and star clusters

During the second and third star reviews, Herschel not only observed Messier objects from the French catalogue. He also occasionally encountered nebulae and star clusters, not already known to him. Most of them were true discoveries. Others had already been found by earlier observers, but Herschel was not aware of this fact. Such cases are generally called 'independent discoveries'. Table 1-18 shows all 22 finds of that period; 12 non-stellar objects were actually new.

Object	Date	S	R	Tel	Con	Type	V	H	Remarks
NGC 2232	5 Dec. 1779	B	2	7-ft	Mon	OC	4.2	VIII 25	D V 14, sw 296 (16 Oct. 1784); Figure 2-57
NGC 869/84	2 Aug. 1780	B	2	7-ft	Per	OC	6.1	VI 33/34	Hipparchus 130 B.C., Double Cluster
NGC 457	18 Aug. 1780	B	2	7-ft	Cas	OC	6.4	VII 42	D III 23, sw 769 (18 Oct. 1787)
M 8	24 Aug. 1780	B	2	7-ft	Sgr	EN+OC	4.6	V 13	Hodierna 1654; the OC is NGC 6530
NGC 6535	24 Aug. 1780	B	2	7-ft	Ser	GC	9.3		Hind 1852
NGC 1981	23 Oct. 1780	B	2	7-ft	Ori	OC	4.2		D II 26
M 47	15 Feb. 1781	B	2	7-ft	Pup	OC	4.4	VIII 38	sw 366 (2 Apr. 1785)
NGC 2264	15 Feb. 1781	B	2	7-ft	Mon	OC	4.1	VIII 5	Christmas Tree Cluster, sw 81 (18 Jan. 1784)
IC 4665	15 Jul. 1781	B	2	7-ft	Oph	OC	4.2		de Chéseaux 1745, C. Herschel 31 Jul. 1783
NGC 2244	22 Oct. 1781	B	3	7-ft	Mon	OC	4.8	VII 2	Flamsteed 1690; sw 114 (24 Jan. 1784)
NGC 2129	6 Feb. 1782	B	3	7-ft	Gem	OC	6.7	VIII 26	D IV 48, sw 317 (16 Nov. 1784)
NGC 7009	7 Sep. 1782	D	3	7-ft	Aqr	PN	8.0	IV 1	sw 228 (16 June 1784), W. Struve 1825
NGC 2169	12 Oct. 1782	D	3	7-ft	Ori	OC	5.9	VIII 24	D I 57, sw 813 (15 Oct. 1784)
M 71	4 Nov. 1782	D	3	7-ft	Sge	GC	8.4		de Chéseaux 1745
NGC 2281	6 Nov. 1782	D	3	7-ft	Aur	OC	5.4	VIII 71	D II 71, sw 813 (4 Mar. 1788)
NGC 2362	4 Mar. 1783	D	3	7-ft	CMa	OC	3.8	VII 17	Hodierna 1654, sw 381 (6 Mar. 1785)
Tr 7	4 Mar. 1783	D	3	7-ft	CMa	OC	7.9		Trumpler 1930
M 79	4 Mar. 1783	D	3	7-ft	Lep	OC	7.7		Méchain 1780
NGC 5195	17 Sep. 1783	D	3	7-ft	UMa	Gx	9.6	I 186	Méchain 1781
NGC 1980	20 Sep. 1783	D		s20-ft	Ori	EN		V 31	ι Orionis Nebula, sw 517 (31 Jan. 1786)
NGC 6802	22 Sep. 1783	D	3	7-ft	Vul	OC	8.8	VI 14	sw 235 (11 July 1784)
NGC 6871	23 Sep. 1783	D	3	7-ft	Cyg	OC	5.2		D III 113, W. Struve 1825

Table 1-18: These 22 non-stellar objects were found by Herschel during the second and third star review ('R'), 12 are true discoveries (bold). S = site: B = Bath, D = Datchet. Type: OC/GC = open/globular cluster, PN = planetary nebula; H = class designation; Remarks: D = double star, sw = sweep.[235]

The first discovery was made on 5 December 1779 in the second review. While inspecting Monoceros with the 7-ft reflector, Herschel saw "over the right [forefoot] 4 or 5 small stars within one Minute". The "right forefoot" is β Mon, identified as double star (I 10 = II 17) in that night. Right after, the small cluster was observed, 2° further north. He catalogued it as 'multiple star' V 14. Actually, this is the open cluster NGC 2232. Herschel again observed it in sweep 296 (16 October 1784) and catalogued it as VIII 25.[236] With a distance of 1060 light-years, the object is Herschel's nearest non-stellar object (see Figure 2-57).

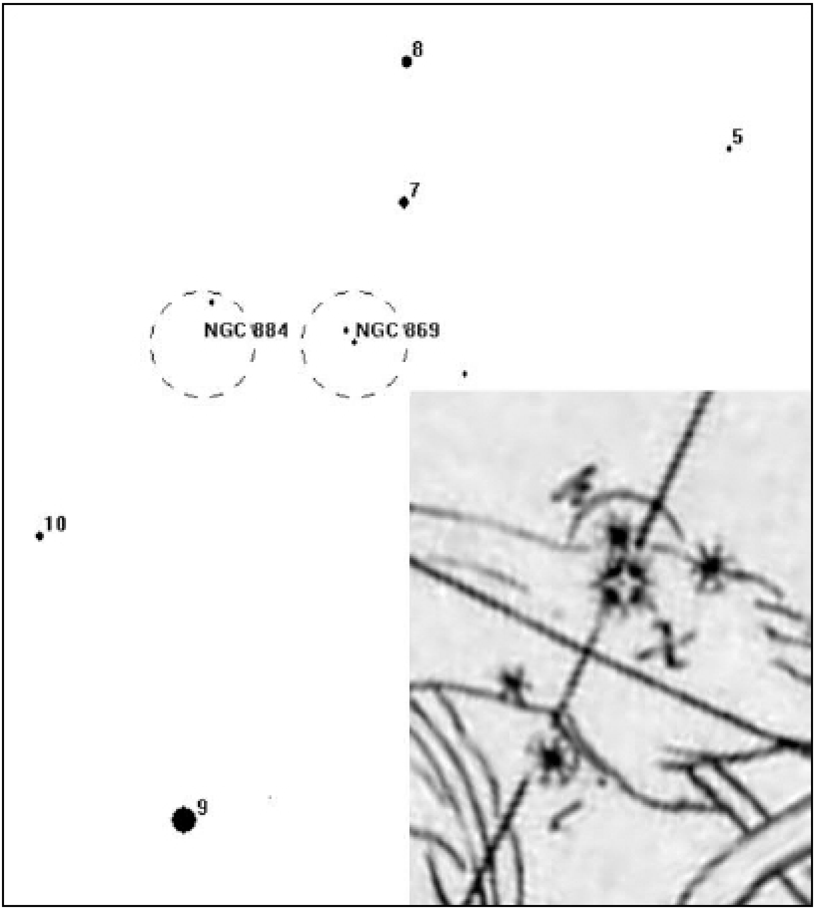


Figure 1-36: The Double Cluster in Perseus, consisting of NGC 869 and NGC 884, is not identical to h and ε Per, as often claimed. The inset is from the northern Harris map. The relevant stars are listed in Table 1-19.

On 2 August 1780, when bringing ε Per into his field of view (diameter 4.5'), Herschel was fascinated: “An astonishing number of small stars, all within the space of a few minutes. I counted no less than 40 within my field of view.” It is interesting that he entered the cluster as a ‘multiple star’ in the first catalogue of double stars, writing ‘VI. 19 ε Persei‘.[237] The object is mentioned in Ferguson’s *Astronomy* as the first of Ptolemy’s ‘Cloudy stars’ (“at the extremity of the right hand of *Perseus*”).[238] It is the famous Double Cluster in Perseus, mentioned by Hipparchus about 130 B.C. and described as

a 'cloudy spot'.239

Bayer	V (B)	Harris	V (H)	Flamsteed	V (F)	V
h	6	*	6	5	6	6.4
χ	5	*χ*	6-7	7 (*χ*)	6-7	6.0
-	-	*h*	7	8	7	5.8
i	6	*i*	6	9 (*i*)	6	5.2v
-	-	*	7	10	7	6.3

Table 1-19: Stars near the Double Cluster in Perseus (see Figure 1-36); V = visual magnitude, estimated by the former astronomers and modern value. 8 and 10 Per were not observed by Bayer. It is interesting that 8 Per was seen so faint by Flamsteed; actually, 9 Per is variable (V747 Per).240

The common name 'h + ε Persei' is supposedly due to Bayer's *Uranometria*, showing a pair of stars at the position, labelled h and ε (the latter is the brighter one). The Harris map also shows the pair. Dreyer catalogued the Double Cluster as NGC 869 and NGC 884. According to the orientation of the stars, the eastern part of the cluster (NGC 869) is identified in the literature as ε Per and the western (NGC 884) as h Per. But this is all wrong! First, comparing the *Uranometria* and the Harris map, Bayer's h Per is not that of Harris (Table 1-19). Second, as Figure 1-36 shows, h Per (no matter if Bayer or Harris) and ε Per are not identical with the Double Cluster. Another observation was made on 20 August 1782 with the 7-ft: "ε Per. with 460, I counted above 20 stars in the field of view." Herschel viewed the Double Cluster again in sweep 877 (1 November 1788) and catalogued it as VI 33/34, not mentioning the former observation. It was seen three times in 1799, not counting the sweeps.

Next came an open cluster in Cassiopeia, NGC 457. Herschel found it on 8 August 1780 in the second review: "a little north of this [ϕ Cas] are several double, treble, quadrupole stars, very small, this is a very rich spot". He identified ϕ Cas as a double star (III 23). Herschel returned to the star four times in 1781–83, but did not mention the cluster. NGC 457 was again seen in sweep 769 (18 October 1787) and catalogued as VII 42.

A few days later, on 24 August, Herschel came across a combination of nebula and cluster in the Milky Way of Sagittarius. After

inspecting a dozen Bayer stars in that constellation with the 7-ft, he saw “a nebula not marked in the [southern Harris] map full of stars in via Lactea [Milky Way] situated in the ecliptic ↗ 25° by my map”. The angle of 25° refers to a longitude scale on the ecliptic (Figure 1-37).

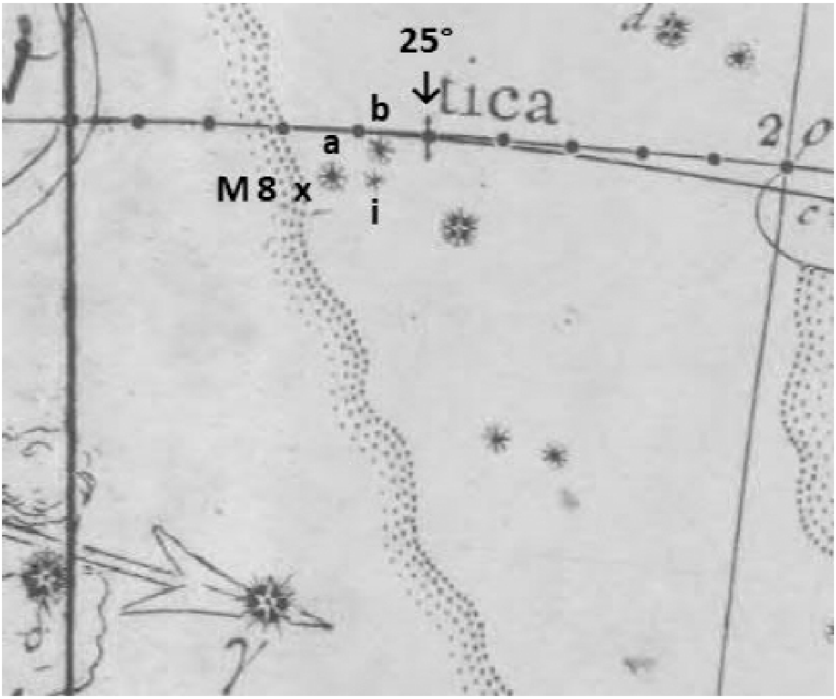


Figure 1-37: Southern Harris map and the place of M 8 (x), near 25° on the ecliptic in the Sagittarius Milky Way. The stars b, i and a are in the *British Catalogue*; now called 4, 5 and 7 Sgr. M 8 coincides with Flamsteed’s 9 Sgr, not plotted on the map. Curiously, 7 (a) Sgr and not 9 Sgr is called ‘Nebulosæ’ in the catalogue (see also footnote 241, below).

No doubt Herschel has seen M 8 and its associated open cluster NGC 6530. Both were discovered by Hodierna in 1654. Ferguson mentions it as one of Flamsteed’s finds, but gives no definite place.[241] Messier saw the object on 23 May 1764 and catalogued it as M 8: “Cluster of stars, which appears in a small refractor of three feet of the form of a nebula; but with an excellent instrument one notices nothing more than a large number of faint stars; near this

cluster there is a pretty bright star, which is surrounded by a faint glow; this is the 9th star in Sagittarius, of 7th magnitude, after Flamsteed; this cluster appears in an elongated form, which stretches from northeast to southwest, between the bow of Sagittarius and the right foot of Ophiuchus."[242]

On 3 May 1783, Herschel saw with the 10-ft: "Two Nebulas close together; I suppose they are Messiers 20th & 21st. Both resolvable into stars; the preceding however leaves no doubt tho' I suppose a higher power & more light would confirm the conjecture. 10ft power 350. The instrument will not conveniently bear a higher so low." However, on 2 August he noted: "I believe [the two nebulae] do not belong to the 20th and 21st but to the 8th Nebula." In that night, he observed M 8, M 20 and M 21 with the small 20-ft. Herschel visited M 8 again in sweeps 223 & 236 (22 May & 12 July 1784); he catalogued the object as 'large nebula' V 13. Dreyer incorrectly credits M 8 (NGC 6532) to Lacaille and the associated open cluster NGC 6530 to John Herschel (h 3725).[243]

Herschel found another nebula in the night of 24 August 1780, while inspecting five stars in 'Serpentarius' (Ophiuchus), noting: "near d [this should read p = 70 Oph] towards Sagittarius, it is a nebula with stars". The object, now belonging to Serpens, is NGC 6535, a globular cluster with a very low star density. This is Herschel's first discovered cluster of this type. He never returned to the object, so it is not included in the catalogues based on his sweeps.[244] Dreyer incorrectly credits NGC 6535 to John Hind, who saw the globular cluster on 26 April 1852 with the 7-inch refractor at Bishop's observatory, London.[245]

When observing λ Aur on 30 September, Herschel noted:[246] "A very rich spot, the nearest about 20" or 30"." It is unlikely that the compact open cluster NGC 1857, about 45' south of the star, is meant (being far out the field of view).[247] Herschel only noticed a pattern of faint stars around λ Aur; so we have no discovery here.

On 23 October, a mixed case was found in Orion: "Above the sword near c the highest of a cluster is double." The double star is II 26, the cluster NGC 1981. Dreyer wrongly credits it to John (h 362), when seen on 4 January 1837. William returned to this place, just north of the Orion Nebula, three times in 1781 (1 and 20 October,

19 November). However, the open cluster was not observed in the sweeps and thus remained uncatalogued.

When inspecting ‘Navis’ (Puppis) and Monoceros on 15 February 1781, Herschel noted: “under the belly [of Monoceros] half way towards Navis a constellation of small stars, double in the finder, one of them is double”. He was not aware that this is the open cluster M 47; the double star is II 63. This happened again on 12 October 1782. Shortly after viewing NGC 2169, Herschel wrote: “Preceding 2 & 4 Navis. Multiple. It is the middle of three stars in the finder. One of the stars among the multiple is of the 2nd class double [II 63].” Later he saw the conspicuous cluster twice in his sweeps 366 and 540 on 4 April 1785 and 19 March 1786, respectively, and catalogued it as VIII 38. However, we cannot blame Herschel for failing the identity with M 47. Messier made a sign error when computing the position, though his description is fine. Therefore, it is not at its true position in the *Atlas Coelestis*: Caroline’s dot is about 3° southeast of M 46, instead of 1.5° northwest.[248]

Also in the night of 15 February, Herschel discovered the open cluster NGC 2264 around the 4.7 mag star 15 Mon: “Ear, a whole constellation of scattered stars.” (The star lies in the ‘ear’ of the mythical creature.) The cluster was seen again on 22 October: “Ear tip surrounded by 5 or 6 stars”. The object, known as the Christmas Tree Cluster, was rediscovered in sweep 81 (18 January 1784) and catalogued as VIII 5.

Herschel found a large open cluster on 15 July 1781: IC 4665 in Ophiuchus: “over β is a fine cluster of small stars”. However, the object was previously observed by de Chéseaux in 1745. Caroline independently saw it on 31 July 1783 with her 4.2-inch sweeper (see next section). The credit was reversed by William, pointing his 7-ft at the object the same night: “1⅓ degree from β Serpentarii towards S. It consists of about 14 to 16 large ones with several very small ones between. 7ft compound [eye] piece. Lina found them. I do not reckon large stars at some distance.” Obviously, he did not remember his find of 1781. The open cluster was not observed in the sweeps. Dreyer incorrectly credits IC 4665 to Solon Bailey, who detected the object on a plate exposed in 1896.[249]

On 22 October 1781 (during the third review) Herschel encountered the open cluster NGC 2244 in Monoceros, not knowing that it had been found by Flamsteed on 17 February 1690 with his mural circle, equipped with a 7-ft refractor of about 2 inches aperture. He wrote: “In Capite Monocerotis or Chin, a very rich spot. One star with at least twelve around it. Multiple.” The star is 12 Mon (5.8 mag). A second observation followed on 13 January 1783: “12 Monocerotis is the cluster of six telescopic stars in pairs but none of them is larger than the 9th or 10 magnitude.” On 29 October, Herschel saw NGC 2244 with the naked eye. The nice cluster was again viewed in sweep 114 (24 January 1784), catalogued as VII 2. Curiously, Dreyer catalogued the open cluster a second time, as NGC 2239, based on John’s observation on 4 March 1830 (h 392), who explicitly refers to his father’s VII 2.

An interesting cluster was discovered on 6 February 1782 in Gemini: “Preceding H Geminorum. The middle of 3 in the finder. Quintuple, in the form of a cross of the 3d class but full 15" I believe.” H Geminorum played a major role in the discovery of Uranus on 13 March 1781 (see section 1.3.2). The quintuple star was entered in the double star catalogue as IV 48. Two observations followed in 1783 (1 January, 24 October). The object is the open cluster NGC 2129, found again in sweep 317 (16 November 1784) and catalogued as VIII 26.

The next object had already been found at Datchet with the 7-ft on 7 September 1782. It is the most famous in the table: the planetary nebula NGC 7009 in Aquarius, later called the Saturn Nebula due to its extraordinary shape (see Introduction). After inspecting his first target, the triple star 13 Sgr, Herschel noted at 9:30 pm:

Preceding ν Aquarii (from ν towards β Capricorni). A curious Nebula, or what else to call it I do not know. it is of a shape somewhat oval, nearly circular, and with this power [460] appears to be 10 or 15″ diameter. It is of the same shape with 278, but much less in appearance. with 932 it is still the same shape but much larger. So that its appearance seems to follow the law of magnifying, from whence it is clear that it is of some real magnitude in the heavens and not a glare of light. The brightness in all the powers does not differ so much as if it were of a planetary

nature, but seems to be of the starry kind, tho' no star is visible with any power. It is all over of nearly the same brightness. The compound eye piece will not distinguish it from a fixt star, at least not sensibly.

Here the term 'planetary' appears for the first time, later used for objects of a similar appearance: pale, round disks, suggesting a planet (like Uranus).[250] Five observations followed in the review period. On 30 September 1782, the nebula was again seen with the 7-ft ("in the same place and of the same shape"). On 25 August, 20 September 1783 and 17 & 23 October 1783 the object was measured with a micrometer eye-piece at the 7-ft. It is astonishing that Herschel had not observed the object with the small 20-ft. On 14 November 1782 (before sweep 20), NGC 7009 was first viewed with the 18.7-inch reflector: "My curious body near ν Aquarii, with the great 20ft. its appearance is very uncommon; it seems like a planetary but ill defined disk, very bright and nearly circular, power 187." Herschel later catalogued the nebula in Aquarius as IV 1, the first entry of his 4th class, 'planetary nebulae'. The object was further observed in the sweep campaign.[251] After performing sweeps 228 and 233, Herschel looked-up NGC 7009 with smaller telescopes (7- and 10-foot). On 15 July 1784 (sweep 238), Herschel used the 18.7-inch again: "My nebula with a disk resembling a small planet." After finishing sweep 314, the 7-ft was used for a measurement. The observations up to that time were summarized in Herschel's paper on the 'construction of the heavens' of 1785; in the chapter 'Planetary Nebulae' we read:[252]

I have examined it with the powers of 71, 227, 278, 460 and 932; and it follows that the laws of magnifying, so that its body is no illusion of light. It is a little oval, and in the 7-foot reflector pretty well defined. In the 20-feet of 18.7 inch aperture, it is much better defined, and has much of a planetary appearance, being all over of an uniform brightness, in which it differs from nebulae: its light seems however to be of a starry nature, which suffers not nearly so much as the planetary disks to do, when much magnified.

Sweep 851 on 2 August 1788 brought news: "The planetary nebula, considerably oval, in the direction of the parallel [east-west] nearly. Of a bluish light, but not very well defined."[253] No further results

appeared in sweep 869 (24 October 1788). From 1799 to 1810, NGC 7009 was observed six times with reflectors of 7, 10 and 20 feet focal length.[254] In 1825, Wilhelm Struve independently found the planetary nebula with his excellent 24.4 cm Fraunhofer refractor at Dorpat.[255] The popular name is due to Lord Rosse. When observing the object on 16 September 1849 with the 72-inch reflector at Birr Castle, he noted: “Saturn nebula. Position of ring 81°”.[256]

The open cluster NGC 2169 was discovered on 12 October 1782: “Making an isosceles triangle with 70 & 67 Orionis [ξ & ν Ori], preceding them. Multiple. A very curious spot. I suspect several of the first class but the air is too tremulous to examine them strictly.” The ‘first class’ double star is I 57. The spot was again observed on 29 October 1782: “Among the several small stars amounting to more than 12 in view, with my power of 460, it is the largest of a triangle, which preceded by four in a line.” Further observations followed on 9 January and 8 March 1783 and 25 January 1802. According to sweep 292 (15 October 1784), the cluster was catalogued as VIII 26.

M 71, independently discovered on 4 November 1782, was discussed in the previous section. Herschel never observed the coarse globular cluster in his sweeps. The object in Sagitta was first seen in 1745 by de Chéseaux.[257] Dreyer lists it as NGC 6838, incorrectly credited to Méchain, who saw the object on 28 June 1780.

The open cluster NGC 2281 in Auriga was found on 6 November 1782: “58^{am} Auriga praecedens. A spot nebulous in the finder is multiple, containing a double star of the 2d class [II 71] and a double of the 3d class. There are about 12 or 14 stars in view with 460.” The spot was again observed on 9 & 18 March (“with 227 about 20 stars in view”) and 17 April 1783. Based on sweep 813 (4 March 1788), the cluster was catalogued as VIII 71.

Spurred on by Caroline’s discoveries when sweeping with a small refractor (see next section), Herschel wrote on 4 March 1783: “I began to sweep the heavens for Nebulas and Clusters of stars. I chose for this purpose the 3½ft achromatic with a single eye lens. The field I suppose is near 50'.”[258] He added: “Note all observations

are to be understood as made with the Achromatic except another Instrument is mentioned.” Later in the report we read: “I swept the place from 16 Navis [16 Pup] to the ears of Lepus, Atlas [*Coelestis*] page 13, within a few degrees of the Horizon, the place being in the Meridian.” However, no distinct result for the small refractor is mentioned. Instead, the night brought about 20 observations with the 7- and small 20-ft reflectors, mainly concerning non-stellar objects; three were found on 4 March.

The first: “30 Canis Majoris [τ CMa], a cluster of stars.” This is the compact open cluster NGC 2362 around the 4.4 mag star (see Figure 5-17). Dreyer incorrectly credits it to Herschel, not knowing about Hodierna’s observation of 1654. The object was seen again in sweep 381 (6 March 1785), catalogued as VII 17. Herschel did not remember his former observation, noting: “A most beautiful cluster of pretty large stars with one of the 7th magnitude in the center which however I suppose does not belong to it.” The second find reads: “About 2 degrees north following 29 Canis, a faint cluster of numberless stars taking up perhaps ½ degree.” There is indeed such an object 2° northeast of 29 CMa: Tr 7, an open cluster catalogued 1930 by Robert Trumpler (see footnote 235). The third object was discovered when Herschel inspected an area in Lepus. At 227× he saw a “cloudy star [which] appears to be a nebula without stars”. He had found the globular cluster M 79 – but was in doubt on 26 March: “What I have set down as a Nebula near β Lep, has probably been a telescopic Comet, for it is no longer to be seen in that place, however the constellation being so low I can not be perfectly sure of its absence.” All became clear on September 28 with the aid of the 7-ft: “79 Nebula of Mess. is that which I discovered March 4th 83”. Herschel never observed the globular cluster in his sweeps. The object in Lepus was discovered by Méchain on 26 October 1780. Dreyer list it as NGC 1904, correctly credited to the French astronomer.

The end of September 1783 brought four discoveries. The first, on the 17th, was made with the 7-ft, when M 51 was observed for the first time (see previous section). Herschel saw a companion of the Messier object, which is obviously NGC 5195: “Two nebula joined together; both suspected of being stars. Of the most north I have hardly any doubt. 7ft 150. A strong suspicion next to certainty of

their being stars. I make no doubt the 20ft will resolve them clearly as they want light & prevent my using a higher power with this instrument. Mr. Messier has only one." Méchain had already noticed the M 51 companion on 31 March 1781, but his observation remained unpublished. Herschel saw it again on 12 May 1787 in sweep 734, catalogued as 'bright nebula' I 186. Dreyer incorrectly credits Herschel in the NGC.

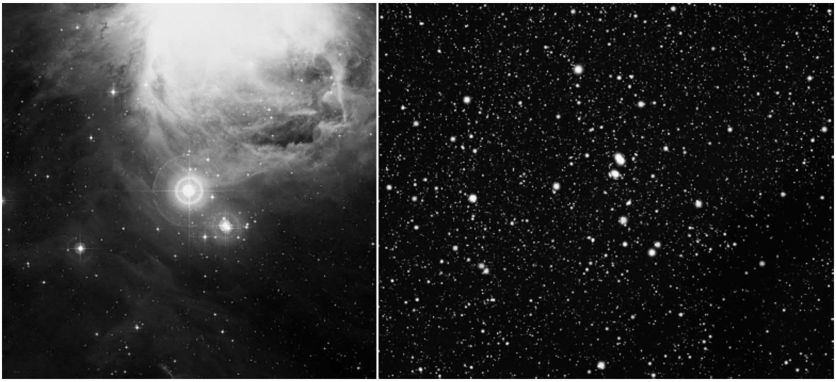


Figure 1-38: Left: Herschel's ι Orionis Nebula V 31 (NGC 1980). It surrounds the 2.8 mag star in the centre, but is only a non-detached part of M 42 (seen north of it). Right: The open cluster NGC 6871 in Cygnus, the last non-stellar object that was discovered in Herschel's third star review.

The second discovery happened on 20 September with the small 20-ft: "43 Nebula. The star under the Nebula in Orion [M 42] is nebulous; or very faintly surrounded with a circular glory of whitish nebulosity. 20ft 200." However, the identification with M 43 is wrong, for this nebula is not "under the Nebula of Orion" (south) but north of it. M 43 was first observed on 3 November 1783 (after sweep 15), but not identified. The nebulous star is ι Ori (2.8 mag), marking the southern end of Orion's sword. Dreyer catalogued the object as NGC 1980, referring to Herschel's 'large nebula' V 31, observed on 31 January 1786 in sweep 517. Herschel wrote: "ι Orionis seems with its neighbouring stars to be involved in milky nebulosity; but it is so faint and the number of stars makes the field so bright, that I cannot assure myself; though I compared this spot with the preceding and following ones." The object, actually a part of M 42, is called the ι Orionis Nebula (Figure 1-38). A star just

north of ι Ori was found to be a multiple (III 12–14) on 7 October 1779 with the 7-ft. On 20 October 1781, it was observed again as ‘double-treble’ (a sketch was made). The nebula is not mentioned.

The third object was found on the 22nd in Vulpecula (‘Anser’): “A course cluster of stars near the 7th Anseris [7 Vul].” This is the open cluster NGC 6802, seen in sweep 235 (11 July 1784) and catalogued as VI 14: “A cluster of exceedingly small stars & very compressed stars in the form of a parallelogram, about 4' long and near 2' broad; in the direction nearly of the meridian.” Herschel’s fourth discovery – and the last one made in the third star review – happened on 23 September 1783 in Cygnus. He noted: “½ degree preceding the above double is one which may be called double-quadruple, or two sets of four stars. Perhaps Fl 27 Cygni.” The multiple star was entered as III 113 in the second double star catalogue. Herschel made another observation on 1 October (“Quadruple & Sextuple”). This actually is an open cluster, which does not appear in Herschel’s catalogues of non-stellar objects (Figure 1-38). Not knowing about his observation, Dreyer catalogued it as NGC 6871. He credits the discovery to Wilhelm Struve, who independently found the object in 1825 with the 24.4 cm Fraunhofer refractor at Dorpat Observatory.

1.9. Caroline’s observations of nebulae and star clusters

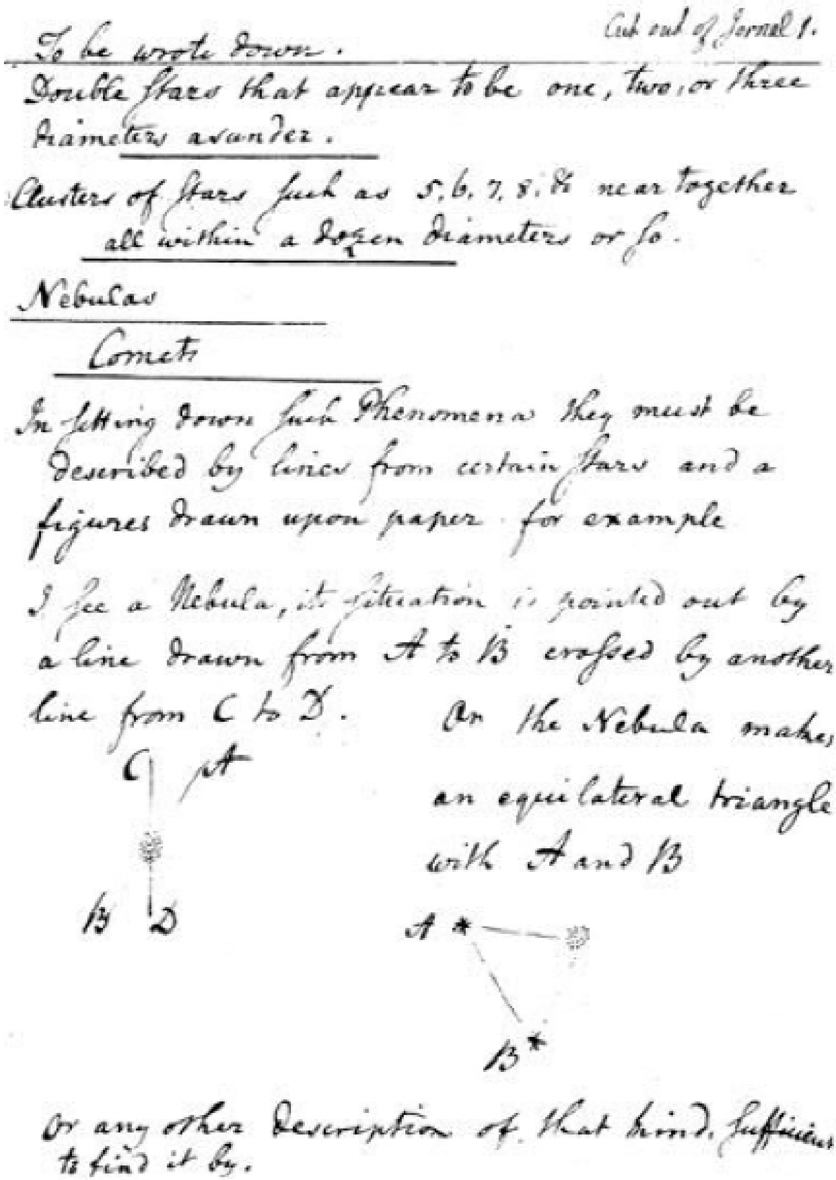
On 28 August 1782, Caroline, now living in Datchet, started her own observations with a small refractor given to her by William. This was not truly voluntary: “I found to be trained for an assistant-astronomer, and by way of encouragement a telescope adapted for ‘sweeping’, consisting of a tube with two glasses, such as are commonly used in a ‘finder’, was given me.”[259] She would search the sky for interesting objects, like double stars, clusters of stars, nebulae and comets. The first page of her *Book of Observations* shows a list of important tasks (Figure 1-39).[260]

No.	Dates	Title	Site	Telescope
1	24 Aug. 1782 – 5 Feb. 1787	*Book of Observations*	Datchet	Rr, SS
2	7 July 1788 – 25 Aug. 1797	*Book of Observations*	Datchet, Clay Hall, Slough	SS, LS
3	25 Aug. 1797 – 31 Jan. 1824	*Book of Observations*	Slough, Hanover (1824)	LS, SS (1824)
4	19 July 1791 – 22 Jan. 1795	*Journal*	Slough	LS

Table 1-20: Caroline's four observing documents (Rr = refractor, SS/LS = small/large sweeper; see Figure 1-40).

For orientation, obedient Caroline used the Harris maps and the *Atlas Coelestis*. She was already familiar with the latter, having labelled all stars bearing a 'Flamsteed number', introduced by William. The task was done during the winter of 1781/82. Additionally, the position of objects from the second *Messier Catalogue* (M 1–70) were marked by a dot, often labelled by an underlined M-number.[261]

With the instructions, she was prepared to make her own celestial observations, though her brother was always near for guidance or to check interesting objects. However, Caroline was often interrupted: "I generally chose my situation by the side of my brother's instrument, that I might be ready to run to the clock or write down memorandums."[262] William mainly used the 7-ft, while the small 20-ft stood idle on the grass-plot. But he had an idea for its use: Caroline could check double stars for mutual motions, using a micrometer. However, due to the telescope's shaky pole mounting, where the observer had to stand freely on a ladder to reach the eye-piece, this was an improper and even dangerous task for a 34-year-old lady. She wrote: "after many fruitless attempts it was seen that the instrument was perhaps as much in fault as my observations." Fortunately, William understood this and terminated the project. When the 18.7-inch reflector was ready for sweeping, Caroline's observations came to an end: "In the beginning of December I became entirely attached to the writing-desk, and had seldom opportunity after that time of using my newly-acquired instrument [small sweeper]."



Cut out of Jornal 1.

To be wrote down.

Double stars that appear to be one, two, or three diameters asunder.

Clusters of stars such as 5, 6, 7, 8, &c near together all within a dozen diameters or so.

Nebulas

Comets

In setting down such Phenomena they must be described by lines from certain stars and a figures drawn upon paper for example

I see a Nebula, its situation is pointed out by a line drawn from A to B crossed by another line from C to D.

Or the Nebula makes an equilateral triangle with A and B

C A

B D

A *

B *

Or any other Description of that kind, sufficient to find it by.

Figure 1-39: William's instructions for Caroline, noted on the first page of her *Book of Observations* (see Table 1-20). She should look for double stars, star clusters, nebulae and comets.

Caroline's small refractor probably had 1.5 feet focal length, implying a lens of no more than 2 inches diameter. This is due to a

remark, made on 22 December 1782: “Swept […] with an 18 inch acchromatic”.[263] The refractor was replaced on 8 July 1783 by the ‘small sweeper’, made by her brother.[264]

This was a 4.2-inch Newtonian with 27 inches focal length (Figure 1-40). At a magnification of 24 it offered a 2.2° field of view (30 × was also often used). With the new tool, Caroline took off. Later, on 13 May 1790, she first used the ‘large sweeper’, a 9.6-inch Newtonian, made by William, with 5 feet focal length; its standard field of view was 1.5°.[265]

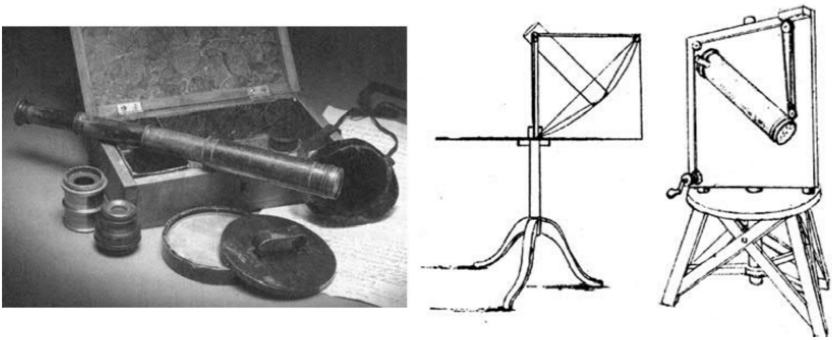


Figure 1-40: Caroline’s telescopes: achromatic refractor (lens ca. 2 inches, 1.5 feet focal length), ‘small sweeper’ (4.2-inch Newtonian. 2.25 feet focal length) and ‘large sweeper’ (9.6-inch Newtonian, 5 feet focal length).[266]

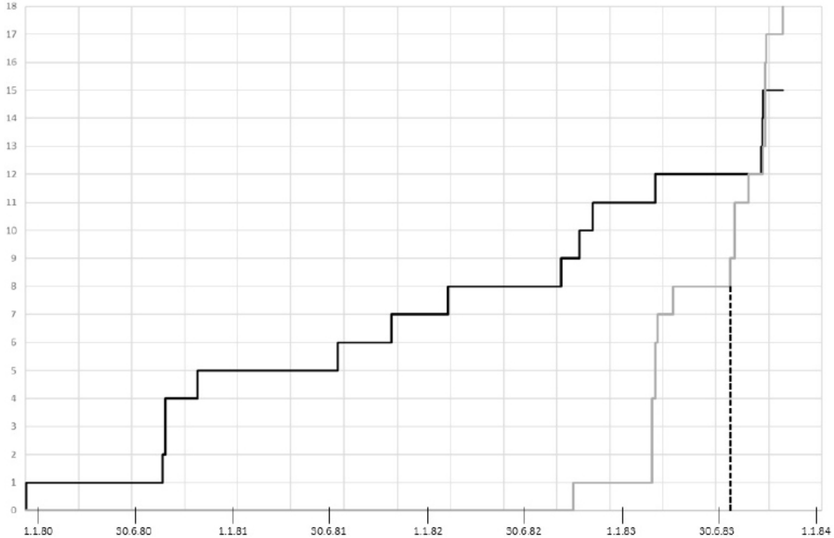
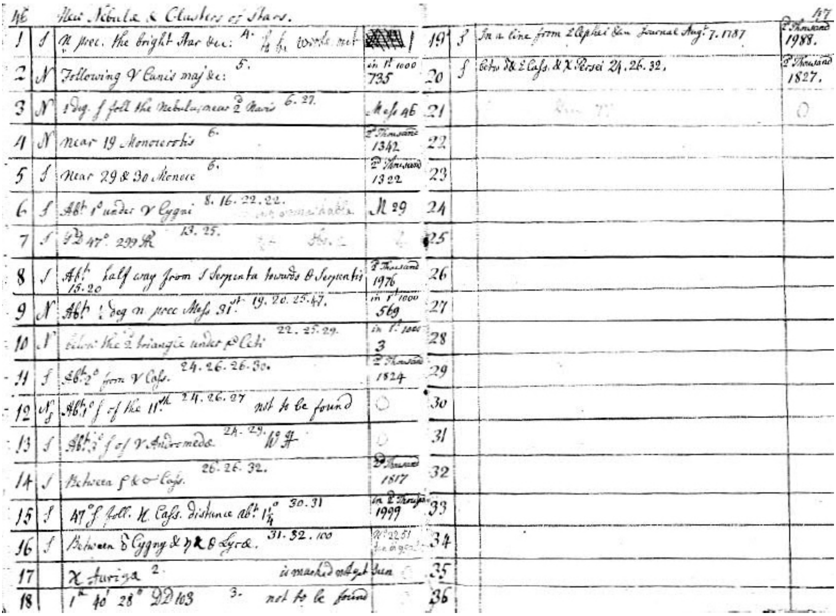


Figure 1-41: Competition of discoveries (number on vertical axis), made between 5 December 1779 and 30 October 1783 by William (black) and Caroline (grey). The dashed line marks the first discovery with the small sweeper (23 July).

Until 29 October 1783, when the sweep campaign started, Caroline had observed on 65 nights. In 60 of them, her brother was observing nearby, working for the third review or inspecting Messier objects. In that period, she made 106 observations of 56 different non-stellar objects. William's score in the same period was 153 observations of 81 objects. 58 of Caroline's observations concern 44 different Messier objects. In the case of new objects, William was leading, but Caroline, starting much later, passed him on the home straight. Figure 1-41 shows the competition, starting on 5 December 1779 with William's open cluster NGC 2232, found in Monoceros, and ending on 30 October 1783 with Caroline's discovery of the open cluster NGC 7789 in Cassiopeia.

In total, Caroline made 329 observations of nebulae and star clusters in 137 different nights. All were made at Datchet and Slough (there was none at Clay Hall). 65 different objects were observed (among the 51 of Messier), many of them more than once. 10 were true and another 12 independent discoveries (Table 1-21); most objects are star clusters. The results are entered in four books,

with sketches of 20 objects. Moreover, Caroline compiled a table, headed ‘New Nebulae & Cluster of Stars’, finally listing 20 entries, roughly sorted by date (Figure 1-42).267



46 New Nebulae & Clusters of Stars. 47

1	ſ	N. prec. the bright Star &c: 4. [illegible]	[illegible]	19	ſ	In a line from ζ Cephei See Journal Aug. 7. 1787	2 Thousand 1988.
2	N	Following γ Canis maj &c: 5.	in 1st 1000 735	20	ſ	betw. δ & ε Cass. & χ Persei 24. 26. 32.	2 Thousand 1827.
3	N	1 deg. ſ foll the Nebula near 2 [illegible] 6. 27.	Mess 46	21			
4	N	near 19 Monocerotis 6.	2 Thousand 1342	22			
5	ſ	near 29 & 30 Monoc 6.	2 Thousand 1322	23			
6	ſ	Abt 1° under γ Cygni 8. 16. 22. 22.	M 29	24			
7	ſ	[illegible] 47° 299 R 13. 25.		25			
8	ſ	Abt half way from ſ Serpenta towards θ Serpentis 15. 20	2 Thousand 1976	26			
9	N	Abt 1 deg [illegible] prec Mess 31st 19. 20. 25. 47.	in 1st 1000 569	27			
10	N	below the 2 triangle under β Ceti 22. 25. 29.	in 1st 1000 3	28			
11	ſ	Abt 2° from γ Cass. 24. 26. 26. 30.	2 Thousand 1824	29			
12	N ſ	Abt [illegible] of the 11th 24. 26. 27 not to be found		30			
13	ſ	Abt [illegible] of γ Andromeda 24. 29.		31			
14	ſ	Between β & [illegible] Cass. 26. 26. 32.	2 Thousand 1817	32			
15	ſ	47° ſ foll. κ Cass. distance abt 1¼° 30. 31	in 2 Thousand 1999	33			
16	ſ	Between δ Cygni & η & θ Lyra. 31. 32. 100	[illegible]	34			
17		χ Auriga 2. [illegible]	[illegible]	35			
18		1h 40' 28° [illegible] 103 3. not to be found		36			

Figure 1-42: Caroline’s list of ‘New Nebulae & Clusters of Stars’.

The night of 30 September 1782, a month after starting the observations, brought a surprise: “Between 18 Sagitta & 12 Vulpecula, a Nebula”.268 The Flamsteed numbers show that Caroline used the *Atlas Coelestis*, in which she had entered them in the winter of 1781/82. William immediately confirmed the object with the 7-ft at 278 ×: Caroline had independently found the bright planetary nebula in Vulpecula, later called Dumbbell Nebula.269

Object	Date	S	Tel	V	Type	Con	Tab	WH	H	Discoverer
M 27	30 Sep. 1782	D	Rr	7.4	PN	Vul		30 Sep. 1782		Messier 12 Jul. 1764
M 93	26 Feb. 1783	D	Rr	6.2	OC	Pup	1	26 Feb. 1783		Messier 20 Mar. 1781
NGC 2360	26 Feb. 1783	D	Rr	7.2	OC	CMa	2	26 Feb. 1783	VII 12	C.H. (I)
M 47	26 Feb. 1783	D	Rr	4.4	OC	Pup		12 Dec. 1782	VIII 38	Hodierna 1654
M 46	4 Mar. 1783	D	Rr	6.1	**OC**	Pup	3	19 Mar. 1786		Messier 19 Feb. 1771
NGC 2311	4 Mar. 1783	D	Rr	9.6	OC	Mon	4	4 Mar. 1783	VIII 60	
M 48	8 Mar. 1783	D	Rr	5.8	OC	Hya	5	8 Mar. 1783	VI 22	Bradley 1727, C.H. (II)
M 29	6 Apr. 1783	D	Rr	6.6	**OC**	Cyg	6	2 Aug. 1783		Messier 29 Jul. 1764
NGC 6866	23 Jul. 1783	D	SS	7.6	OC	Cyg	7	16 Oct. 1783	VII 59	
IC 4665	31 Jul. 1783	D	SS	4.2	OC	Oph		15 Jul. 1781		de Chéseaux 1745
NGC 6633	31 Jul. 1783	D	SS	4.6	OC	Oph	8	30 Jul. 1788	VIII 72	de Chéseaux 1745, C.H. (II)
NGC 205	27 Aug. 1783	D	SS	8.1	**Gx**	And	9	24 Oct. 1783	V 18	Messier 10 Aug. 1773, C.H. (I)
NGC 253	23 Sep. 1783	D	SS	7.2	**Gx**	Scl	10	23 Sep. 1783	V 1	C.H. (I)
NGC 225	27 Sep. 1783	D	SS	7.0	**OC**	Cas	11,15	26 Nov. 1788	VIII 78	C.H. (II)
NGC 189	27 Sep. 1783	D	SS	8.8	OC	Cas	12			
NGC 663	27 Sep. 1783	D	SS	7.1	OC	Cas	20	3 Nov. 1787	VI 31	
NGC 752	29 Sep. 1783	D	SS	5.7	OC	And	13	24 Aug. 1783	VII 32	Hodierna 1654
NGC 7789	30 Oct. 1783	D	SS	6.7	OC	Cas	14	18 Oct. 1787	VI 30	C.H. (II)
NGC 6819	12 May 1784	D	SS	7.3	**OC**	Cyg	16			W. Herschel 30 Dec. 1806
NGC 7380	7 Aug. 1787	S	SS	7.2	OC	Cep	19	1 Nov. 1788	VIII 77	C.H. (II)
NGC 4449	8 Jul. 1793	S	LS	9.6	**Gx**	CVn		27 Apr. 1788	I 213	W. Herschel (sweep 833)
NGC 2403	31 Jul. 1793	S	LS	8.5	**Gx**	Cam		1 Nov. 1788	V 44	W. Herschel (sweep 879)

Table 1-21: Caroline found 22 non-stellar objects (bold = 10 discoveries). S = site: D = Datchet, S = Slough; Tel: Rr = refractor, SS/LS = small/large sweeper. Some were sketched (bold Type), OC = open cluster, PN = planetary nebula, Gx = galaxy; Tab = number in her table (Figure 1-42); WH = first observation; H = catalogue designation. Discoverer: C.H. = William's credit in his first (I)/ second catalogue (II).

On 29 October, Caroline saw "A Nebula between β and θAuriga; south following the line". William identified it as the open cluster M 37 in Auriga the same night.[270] It is not counted as an independent discovery. She observed the bright cluster again on 4 & 6 November and 28 December.

No new Messier object was seen until 26 February 1783. In that night, Caroline found the open cluster M 93 in Puppis ('Navis') and William confirmed it with the 7-ft. She wrote: "Nebula, about 1¼ deg north preceding the bright star in the Ship preceding the 1st Navis of Fl. towards 23 [γ] Canis Majoris. My Brother examined it with 460 and found not less than 20 stars, with 227 above 40, with a compound eye piece perhaps 100 or 150 and very beautiful, nothing nebulous among them. Messier has it not." The "bright star in the Ship" is ξ Pup. M 93 was unknown to the Herschels, because the final *Messier Catalogue* had not yet reached them.

On 26 February 1783, Caroline made her first own discovery: "Following γ Canis majoris a very faint Nebula". The small refractor showed the open cluster NGC 2360 (Figure 1-43).[271] It was immediately checked by William with the 7-ft at 227× and 460×. Caroline copied the description in her first *Book of Observations*. The object is listed as no. 2 in her table and was later catalogued by William as VII 12 (sweep 366). Dreyer correctly credits NGC 2360 to Caroline. In the same night she noted: "Observed a nebula near the 2d Navis [2 Pup], a cluster of bright stars. (Mess. 46)." She entered the object in the *Atlas Coelestis*, located about 1° west of the star.

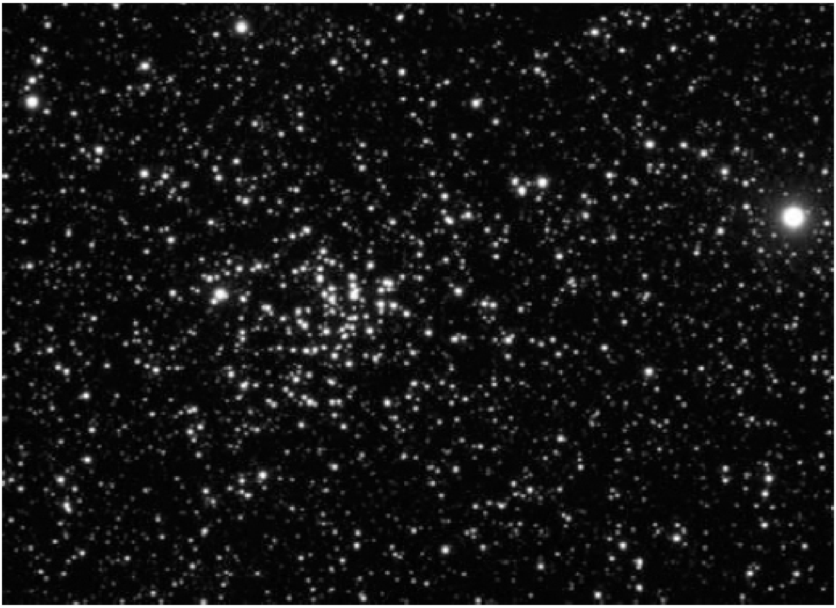


Figure 1-43: Caroline's first own discovery, the open cluster NGC 2360 in Canis Major, found on 26 February 1783 with her small refractor (the 5.5 mag star to the right bears no Flamsteed number).

4 March 1783 was an interesting night; Caroline's observing book shows four entries.[272] The first reads: "I began to sweep at 7 o'clock (η Gemin. on the meridian) about 8 or 10 degrees on both sides of the meridian, as low as my situation would allow." At that time, the star η Gem was 60° above the horizon. At about 8 pm, when going 40° south, she encountered a nebulous object near 2 Pup ('Navis'):

"1 deg. south following the nebula near the 2d Navis, a Nebula, the figure is done by memory. My Brother observed it with 227 and found it to be an astonishing number of stars, it is not in Mess. Catalogue." Obviously, Caroline has seen two different objects near 2 Pup: the first was called 'Mess. 46', a second followed. There are indeed two non-stellar objects in the area: M 46 and M 47. However, M 47 was plotted by her in the *Atlas Coelestis* about 1° southeast of the 6.7 mag star. This is due to a position error in the *Messier Catalogue*. Actually, M 47 is 2° west of the star and M 46 lies right between them (Figure 1-44).

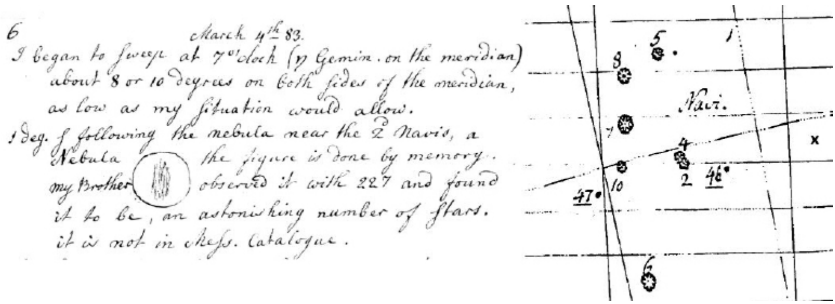


Figure 1-44: M 46 and M 47 in 'Navis' (Puppis) are marked by Caroline in the *Atlas Coelestis*. The position of M 47 is wrong, due to Messier; the correct place (x) is west of M 46.

Thus, Caroline has first seen M 47 (on 26 February) and now, on 4 March, both M 46 and M 47. Therefore, the two open clusters can be counted as independent discoveries. Of course, only M 46 is listed in her table (no. 3). On 19 November, she was sure: "My 3d nebula is Mess 46th" (referring to all objects of 26 February and 4 March). Although William had confirmed his sister's observation, M 46 was rediscovered on 19 March 1786 in sweep 540. Moreover, he had already seen M 47 on 15 February 1781, not knowing about its identity (see previous section). Due to the amount of observational data, it was rather difficult to keep track of all objects. Dreyer incorrectly credits M 47 to William.

Caroline's third entry of the night of 4 March describes an actual discovery: the open cluster NGC 2311 in Monoceros (no. 4 in her table). She wrote: "In the neighbourhood of the 17 Monoceros, a Nebula, very obscure. Mess. has it not." The cluster is 1.5°

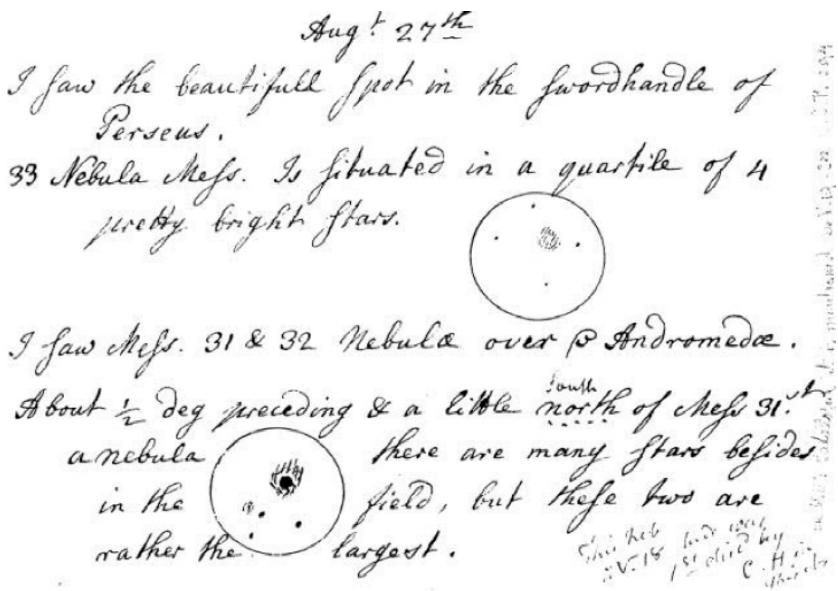
southwest of the star. William checked it immediately with the 7-ft.[273] It was later catalogued as VIII 60 (sweep 639).[274] Dreyer incorrectly credits NGC 2311 to him. Caroline's fourth entry reads: "I left off sweeping 9 o'clock about 1 degree above κ Orionis." The star (Saiph) was 45° west of the meridian, 17° above the horizon.

M 48 and M 29 were seen by Caroline, not knowing their identity. However, both are marked by a dot in the *Atlas Coelestis*. On 8 March 1783 she noted: "I began to sweep from α Hydrae (when it was nearly in the meridian) upwards, left off at Procyon, I swept about 15° on each side of the meridian. At an equal distance from 29 & 30 Monocerotis [ζ Mon & 1 Hya], making an equilateral triangle with those two stars is a nebulous spot. By the telescope it appears to be a cluster of scattered stars, it is not in Mess. catalogue." This is the open cluster M 48 in Hydra, checked by William the same night (later catalogued as VI 22). Caroline entered the object as no. 5 in her table. Dreyer incorrectly credits M 48 to her. The open cluster M 29 in Cygnus was found on 6 April: "About 1 degree under γ Cygni; in my telescope 5 small stars, my brother looked at them with the 7ft and counted 12. It is not in Mess. catalogue." She made a sketch. Curiously, there is a dot in the *Atlas Coelestis* at the correct position but no label. Caroline "saw the little cluster of stars under γ Cygni" again on 2 August, now with the 4.2-inch sweeper. William did so too: "29 Nebula M. Sweeper 30 [power]. Some small stars, a dozen or more." Though the identity was clear now, Caroline noted on 22 September: "Near 1½ degree south following γ Cygni towards i [41 Cyg], I saw 4 stars, the evening bad, April 6th I counted 5." On her last observation (19 December 1788), she eventually mentions the "29th of the Conoiss.". M 29 was never seen in the sweeps.

On 23 July 1783, Caroline briefly noted: "PD 47°, 299 AR. Some small stars; or perhaps a Nebula." Place and description match the open cluster NGC 6866 in Cygnus. This was her first discovery with the new Newtonian sweeper of 4.2 inches aperture. On 16 October, she wrote: "My brother shewed me the spot in Cygnus, which I saw first July 23, the stars very numerous, and intermixed with strong nebulosity. Mess. has it not." William used the 7-ft, as mentioned in his own record; he later catalogued the cluster as VII 59 (sweep 959, 11 September 1790). Dreyer incorrectly credits NGC 6866 to

William.

On 31 July, Caroline independently found two open clusters in Ophiuchus, already discovered by de Chéseaux in 1745: IC 4665 and NGC 6633, both seen with the sweeper. Caroline wrote in her observing book: “From β Serpentarii [β Oph] towards S [72 Oph], 1⅓ degree; a cluster of stars. I counted about 50 in the field; rather more than less (my Brothers).” William had seen IC 4665 already on the 15th (see previous section). Caroline’s note for NGC 6633 reads: “About half way from S Serpentarii [72 Oph] towards θ Serpentis, a cluster of large stars. I counted about 80. Mess. has it not.” On 12 September, she wrote: “Saw the new cluster of stars between θ Serpentis & S Serpentarii. With a power of 54 I counted between 20 & 30 stars (the Moon was bright). A pretty object on account of the stars seeming so equal in collour [sic] and magnitude. I did not include one large redish star to the left; nor others at more distance in the field.” The cluster is no. 8 in her table; William catalogued it as VIII 72 (sweep 850). Dreyer credits IC 4665 to Bailey and NGC 6633 to Caroline, which are both incorrect.



Augt 27th

I saw the beautifull spot in the swordhandle of Perseus.

33 Nebula Mess. Is situated in a quartile of 4 pretty bright stars.

I saw Mess. 31 & 32 Nebula over β Andromedæ.

About ½ deg preceding & a little north south of Mess 31st a nebula there are many stars besides in the field, but these two are rather the largest.

Figure 1-45: Caroline’s entry of 27 August 1783 in her first observing book shows sketches of M 33 and NGC 205, discovered in that night. At the lower right, she later added: “This Neb. is V 18

that was 1^{st} discov. by C.H."

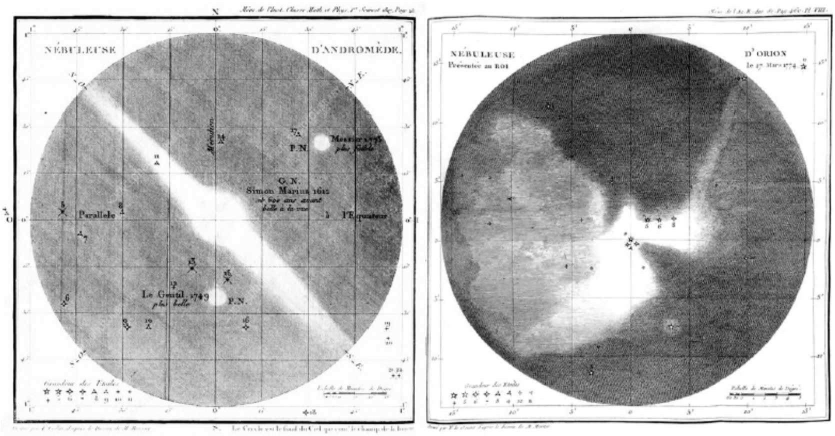


Figure 1-46: Messier's drawings of the Andromeda Nebula and the Orion Nebula. In the former, NGC 205 (M 110) is seen northwest of M 31.[275]

On 27 August, Caroline viewed the "beautiful spot in the swordhandle of Perseus" (Double Cluster) and M 33, making a sketch. Soon after she saw the Andromeda Nebula – and discovered its fainter companion, NGC 205 (Figure 1-45). Messier had found the 8.1 mag elliptical galaxy on 10 August 1773, but did not publish the observation until 1798 (Figure 1-46).[276] Caroline: "About ½ deg preceding & a little north of Mess. 31, a nebula, there are many stars besides in the field, but these two are rather largest." This refers to the sketch. She listed the object as no. 9 in her table. Caroline returned to the nebula near M 31 four times.[277] William saw it first on 24 October 1783: "There is a faint nebula about 2/3 degree north preceding Messiers 31^{st}; in a line parallel to β and ν Andromeda. My sister found it. With 7ft 100 I suspect it to consist of stars, but will want a great deal of light to resolve it." He catalogued it as 'large nebula' V 18 (sweep 282).[278] Dreyer incorrectly credits NGC 205 to Caroline.

In late September 1783, Caroline made five discoveries with her fine Newtonian sweeper. On the 23^{rd} she noted: "A faint Nebula below the 2d triangle under β Ceti in the direction parallel to θ & τ, under the two preceding stars of the 2d triangle nearly at an equal

distance. Mess. has it not.” She made a sketch (Figure 1-47).

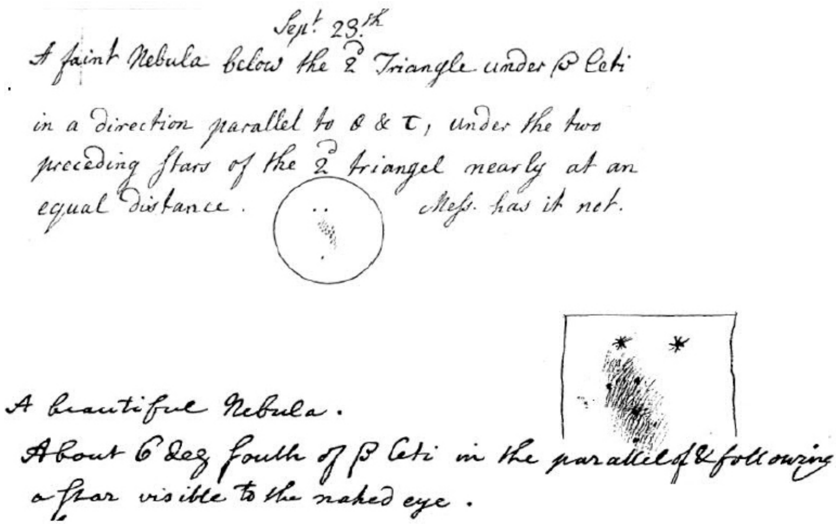


Figure 1-47: On 23 September 1783, Caroline made her most important deep-sky discovery: NGC 253 in Sculptor, seen and sketched with the small sweeper (above). On 30 October (sweep 8), William viewed the nebula in the new 20-ft and made a sketch (below).

This is the 7.2 mag galaxy NGC 253 in Sculptor.279 William checked it immediately and gave a comprehensive report: “My sister discovered a new Nebula.” He first describes the problem of finding it, for there are no Flamsteed stars around. Then he wrote: “With the 7ft 57 it appears like a nebulous spot lengthened out to a considerable extent from south preceding to north following, with 20ft 200, it is resolved into small stars 8 ort 10 whereof may be counted the rest are too small and crowded to be distinguished & lose themselves in seeming nebulosity. The observation was made when the spot was about an hour past the meridian.” The time was about 1 am, the nebula had an altitude of only 9°. On 27 October, Caroline viewed it again: “I saw the Nebula under the two triangles below Baten Ketos.” The star name is incorrect (Baten Kaitos is ζ Cet). A last observation was made on 13 December. William saw the nebula with the 18.7-inch reflector on 30 October in sweep 8. However, the circumstances were curious. When performing horizontal sweeps in Cetus he saw “A beautiful Nebula” (Figure

1-47). After describing the view (“On looking at the nebula a long while the suspicion of its consisting of stars grows stronger as it begins to put on a faintly mottled appearance.”), he wrote: “I looked for my sisters Nebula of the 23 of Sept. 1783 & to my surprise found it to be the above, the difference in the appearance being so very considerable that I have not the least idea of their being the same tho’ I knew they could not be far asunder.” NGC 253 was catalogued as V 1, the first object of William’s 5th class, ‘large nebulae’. It was again observed in sweeps 467 and 593. Dreyer correctly credits the galaxy to Caroline.

27 September brought three discoveries, all are star clusters in Cassiopeia; Caroline noted that “Mess. has them not.” William was not involved in that night; he entertained the Scottish astronomer Patrick Wilson with several objects. Although Caroline’s descriptions are confusing, their identity could be confirmed. However, due to the many open clusters in this constellation, this was a difficult task.

Caroline’s first entry reads: “About 2 degrees from γ Cassiopeia, making an isosceles triangle with γ & κ, a small cluster of stars, seeming to be intermixed with nebulosity.” There are two open clusters in the field: NGC 189 and NGC 225 (Figure 1-48).

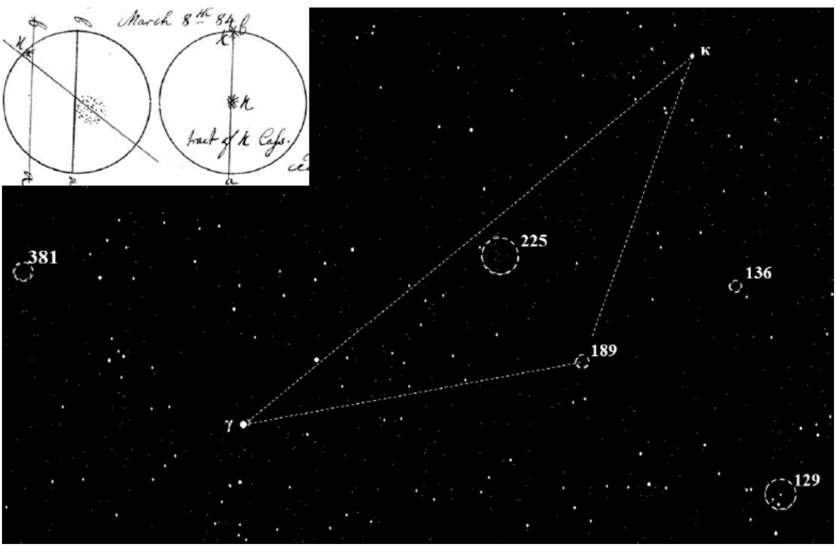


Figure 1-48: Three candidates for Caroline's find of 27 September 1783 in Cassiopeia (see text): the open clusters NGC 189, NGC 225 and NGC 381. The distance between κ and γ Cas is 3.6°. The a–b line refers to the sky motion.

The description favours the former, because the latter is more midway between the stars. However, the next observation (30 October) fits much better to NGC 225: "1½ degree from γ towards κ Cass. (by the finder) the first cluster of Sept. 27th." On 1 November, Caroline wrote: "I saw the cluster of small stars near γ Cassiopeia but could not see the faint nebula near the cluster." On 23 February 1784, there are two entries: "I looked for the two clusters of stars near γ Cassiopeia (see Sept. 27th 83) but could not find them; some clouds interfering." and "I saw a cluster of obscure stars about 1½° south preceding κ Cassiopeia. My brother observed it with the 7 feet, and counted 20 stars." The second entry again favours NGC 225 (William's observation is otherwise documented). On 8 March 1784, Caroline noted: "When κ Cassiopeia is just going out of the field, the cluster is a little advanced as in the Fig. By the delineation [sketch] it seems to be 47° south following κ Cassiopeia at the distance of about 1¼ degree." This was confirmed on 11 March 1784: "I saw the cluster near κ Cassiopeia and found it instantly by the description of the 8th of March." Caroline was confused: the object, seen four times (27 Sep., 30 Oct. and 1 Nov. 1783, 23 Feb. 1784), is listed as no. 11 in her table: "About 1° from γ Cass. 2d Thousand 1824". The object of 8 & 11 March 1784 is no. 15: "47° foll. κ Cass. distance 1¼°. In 2d Thousand 1999". What does the additional information mean? "2d Thousand" refers to Herschel's second published catalogue of nebula and clusters; 1824 and 1999 refer to Caroline's 'General number', chronologically numbering William's discoveries in the sweeps (see section 2.1.6): no. 1824 is NGC 381, no. 1999 is NGC 225. Obviously, she identified her first discovery with a different cluster. However, NGC 381 is located 1.5° northeast of γ Cas and 4.3° southeast from κ Cas, which does not match her data.[280] Therefore, we end up with NGC 225. The open cluster was first seen by William on 12 March 1784 with the 7-ft at 57× before starting sweep 165. He later catalogued the object as VIII 78 (sweep 887).

Now, what is the "faint nebula near the cluster"? On 27 September

1783, we read: “About 1° south of the above cluster [NGC 225] a faint nebula surrounded with a great number of both large and small stars, there are more large stars in the field than are marked here [sketch] but I took particular notice of the two between which the nebula is situated.” This points to NGC 189, about 1° southwest – there is no other object. On 30 October, Caroline wrote “I saw Sept. a faint nebula surrounded with a great number of stars near the above cluster; but could not find it to night, evening is not very fine.” So we have only one observation (no. 12 in her table). William never saw NGC 189. Dreyer incorrectly credits NGC 189 to John (h 36).

A third cluster was found on 27 September: “δ and ε Cassiopeia & ε Persei making a trefoil, a cluster of stars in the middle.” There are three candidates: NGC 659, NGC 663 and NGC 743; none is in the middle of the triangle. On 30 October, we read: “I saw the cluster which is placed between δ & ε Cassiopeia and ε Persei (a crowded place).” And on 9 April 1785: “I saw the cluster between δ & ε Cassiopeia & ε Persei, the stars are not many, but they are striking & seem to have some nebulosity.” Concerning the place, NGC 743 is the best fit, but John (h 170) describes it as a “poor cluster” (William had not seen it). NGC 659 does not form an isosceles triangle with δ & ε Cas, but NGC 663 looks fine. William has seen both clusters in sweep 774 (3 November 1787). NGC 659 (VIII 65) is described as “small cluster of small stars, not very rich” and NGC 663 (VI 31) as “A beautiful cluster of pretty large stars near 15’ diameter and considerably rich”. From the description, NGC 663 seems to be Caroline’s object (no. 20 in her table).[281] Dreyer credits NGC 659 to Caroline and NGC 663 to William – both are incorrect.

There is no doubt that Caroline found the open cluster NGC 752 in Andromeda on 29 September. William had seen it already on 24 August, but the actual discoverer is Hodierna (1654). Caroline noted: “About 3° south of γ Andromeda, a fine cluster of stars. Mess. has it not.” Another observation followed on 13 December (“my cluster of stars under γ Andromeda”). William had written on 24 August: “Cluster of stars near 56 Andromeda, very rich, Messier has it not.” He saw the cluster with naked eye on 30 October. When NGC 752 was observed in sweep 599 (21 September 1786), it was catalogued as VII 32. Dreyer incorrectly credits William as

discoverer.

The open cluster NGC 7789 in Cassiopeia is an actual discovery by Caroline, the last in her phenomenal year of 1783 at Datchet (Figure 1-49). On 30 October, she wrote: “Between σ & ρ Cassiopeia a fine nebula, very strong.”

She viewed the object again on 1 November; a final observation was made on 9 April 1785: “I saw the nebula between ρ & σ Cassiopeia large and strong, but no stars visible in my telescope.” William observed the open cluster on 12 March 1784 with the 7-ft at 57 × before starting sweep 165. It was again seen in sweep 769 (18 October 1787) and catalogued as VI 30. Dreyer correctly credits NGC 7789 to Caroline.[282]

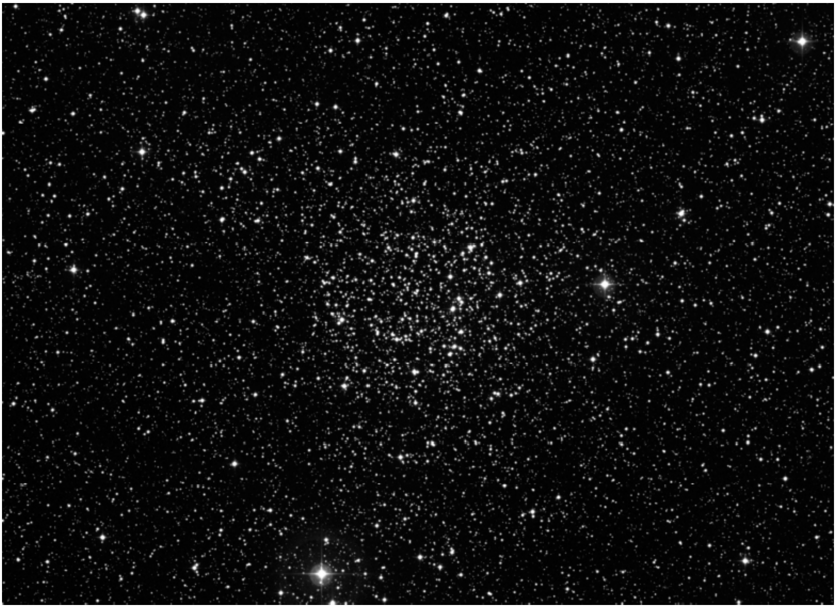


Figure 1-49: Caroline’s open cluster NGC 7789 in Cassiopeia, discovered on 30 October 1783 with the small sweeper. The spectacular object is sometimes called Caroline’s Rose.

On 29 October, William started his sweeps and Caroline was increasingly more involved in that mission, leaving little time for her own observations. However, on 12 May 1784 she discovered “a small Nebula. There are very few stars near it in Fl[amsteed] but

the 14 Cygni is not far off, in the field with the neb[ula] are a great many small stars, & some much brighter; but the bright ones almost all of an equal size [...] the place is about half way between δ Cygni & η [Cygni] & θ Lyra making an isosceles triangle downwards". A sketch was made (Figure 1-50). This is the open cluster NGC 6819.

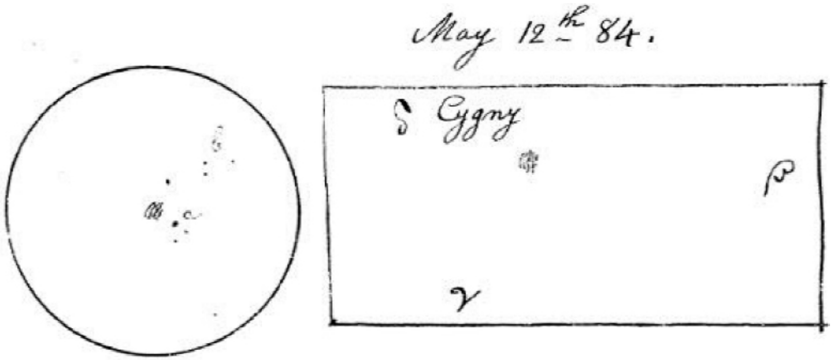


Figure 1-50: Caroline's sketch of the open cluster NGC 6819 in Cygnus, discovered with the small sweeper on 12 May 1784.

Two days later Caroline noted: "I suspect that the small nebula of the 12th might have been a comet, therefore was much disappointed last night it was cloudy; but it proved to be a small nebula situated near the small triangles in the figure of the 12th. My Brother shew'd it to me in the 7 feet & there it appeared to be small stars mixed with nebulosity." There is no record by William about this observation. Moreover, the object is missing in the sweeps. However, he actually saw it on 31 December 1801 with the 10-ft reflector: "There is a scattered cluster of very small stars about 2° 10' from 14 Cygni towards η (21). My sister saw it May 12, 1784. The small triangle with one bright star is in the field with it, and the bright star is visible in the finder. See her figure of it. The cluster is pf a very irregular figure."[283] Caroline copied this text in the third observing book, adding "10 feet (my number 16)".[284] The object is no. 16 in her table. William made another observation on 30 December 1806: "10 feet. There is a cluster of very small stars preceding 19 Cygni & in a line between γ Cygni and η Lyra." He was not aware that this is the object of 1801. Dreyer noted 'Harding 1827' for NGC 6819 and also gives John's observation of 1831 (h 2048).[285] Harding actually saw the cluster in 1823 – but the true

discoverer is Caroline!

It took three years for another discovery. On 7 August 1787 Caroline saw the open cluster NGC 7380 in Cepheus, noting: “I saw a nebulous patch in a line from ε Cephei continued thro’ δ towards 1st and 2nd Fl[amsteed] Cassiopeia.” It is no. 19 in her table. William catalogued the cluster as VIII 77 (sweep 876, 1 November 1788). Dreyer correctly credits NGC 7380 to Caroline.

Another find was made on 8 July 1793 with the ‘large sweeper’ (9.6-inch Newtonian; Figure 1-40), equipped with a double eye-piece that had triangular wires. While viewing in Canes Venatici, Caroline came across a ‘comet’ near an anonymous star, called ‘a’ on her sketch (Figure 1-51). The next night (9th) it was found that the object “remains in the same place it is near a star of about the 7 mag. not in Fl. Atlas.” The position was described against star ‘a’, β CVn and a ‘cluster’ of stars. On the 10th, star ‘a’ was seen “in a line with 2 and 4 Canum Ven. and nearly at the same distance from 4, as 4 is from 2.” The stars are real and the Caroline’s ‘comet’ is undoubtedly the 9.6 mag galaxy NGC 4449. It was previously discovered by William on 27 April 1788 (sweep 833) and described as “very brilliant”, showing four condensations.[286]

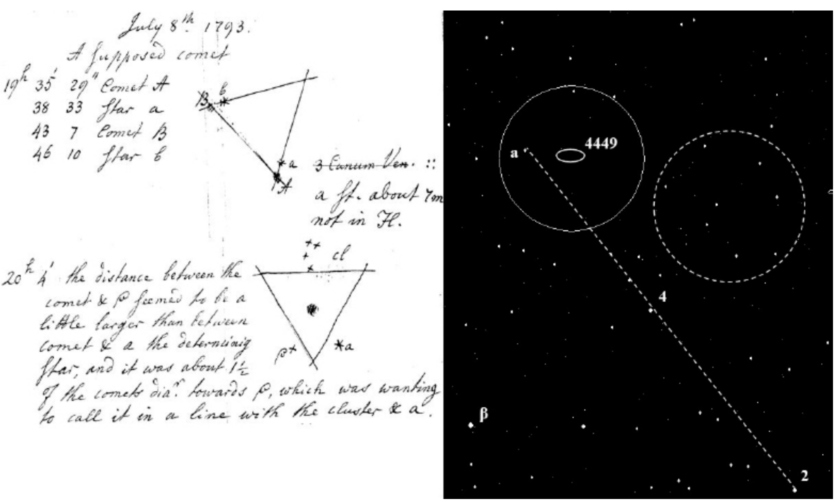


Figure 1-51: Caroline’s observations of a ‘supposed comet’ in Canes Venatici on 8 July 1793, made with the large sweeper; the eye-piece had triangular wires and 1.5° field of view (circle). The

discovered object is the galaxy NGC 4449. The dashed circle marks the mentioned 'cluster'; the dashed line leads from 2 and 4 CVn to star 'a'; β CVn is in the lower left corner.

On 31 July 1793, Caroline wrote: "I began to sweep as soon as it was dark enough with υ Ursa maj. I found a small nebula, which detained me for near an hour, on the next page is its situation to the naked eye, and the field of view of the small double eye piece. After I had made the following pictures and could perceive no motion in the object I continued to sweep towards the east and left off, when daylight was too strong." This is a puzzling case. The naked eye situation shows three stars, labelled '42 Lyncis', '43' and 'Ursa o' (Figure 1-52). Looking at 42 and 43 Lyn the third star should be λ or μ UMa. A careful investigation shows that Caroline's identification must be wrong. Actually, '42 Lyn' is the upper one, the Ursa Major star is northeast and, moreover, the trio stands at sidereal time 20^h 8' (11:40 pm) only 6° above the northern horizon (υ UMa is 19° further north). The only galaxy in the triangle, NGC 3104, is too faint and does not fit the sketched star pattern.[287]

However, when taking "Ursa o" as the star ο UMa (located 10° west of υ UMa), we find two stars labelled 42 and 43, giving an acute triangle in the right direction. However, these are 42 and 43 Cam. This trio was about 30° above the horizon at the time. Is there a nebula inside the triangle? Indeed, the 8.5 mag galaxy NGC 2403. Looking at the surrounding stars and rotating the field 180°, the pattern matches Caroline's sketch! The field of view is 45', thus the standard eye-piece (1.5°) was not used. William had discovered the object already in sweep 879 of 1 November 1788 ("resembling a star with a misty atmosphere"). He catalogued it as 'large nebula' V 44; Dreyer correctly credits William for NGC 2403.

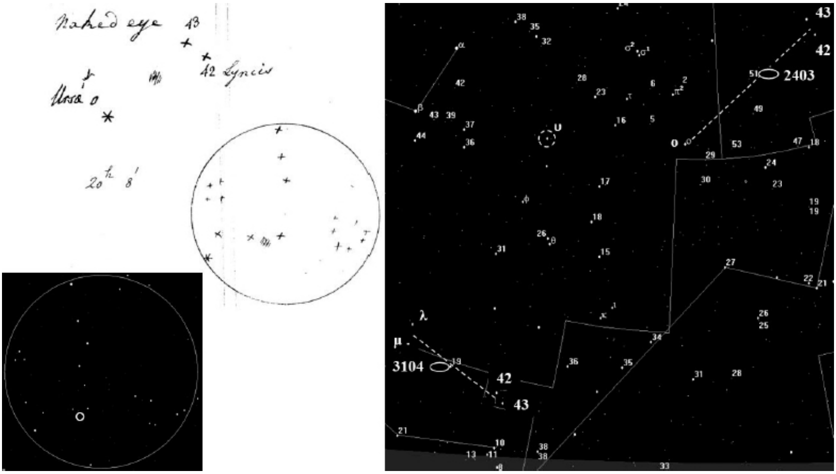


Figure 1-52: Caroline's observation of NGC 2403 in Camelopardalis. The sky map (horizontal view) shows the wrong trio (42 and 43 Lyn and λ or μ UMa) about 6° above the horizon (grey); the galaxy NGC 3104 in between is too faint. υ UMa (circle) is 19° above. The correct trio is 16° to the right: 42 and 43 Cam and ο UMa; there we find NGC 2403.

On 7 August 1783, Caroline observed M 40 in Ursa Major with the small sweeper: "Mess 40 Nebula by δ Ursa majoris; consists only of two small stars." She had marked it as a dot (without number) in the *Atlas Coelestis* (Figure 1-53), though it is 28' southeast of catalogued position. Perhaps this is due to the precession of Messier's coordinates to Flamsteed's equinox 1690. But it is not clear whether she was aware of the fact that the positions in the *Messier Catalogue* are for the discovery date, so that there is no uniform equinox. However, she must have seen the correct pair in the 2.2° field of her small sweeper.

The story of M 40 is interesting. Found by Messier on 25 October 1764, it is among his 'missing' objects. In 1862 Arthur Auwers, who first reduced the position to a common equinox 1830, noticed that there is a pair of stars at the place:[288] "Two close stars, found when searching for a nebula mentioned by Hevel, who obviously has seen the pair as a single star." Indeed, Johann Hevelius had catalogued the object as 'nebulous' in his star catalogue *Prodromus Astronomiae* of 1690 (entry no. 1496). Independently, Auwers' friend Friedrich

Winnecke[289] discovered a double star in Ursa Major at Pulkovo Observatory on 12 December 1863, using the 38 cm Merz refractor at 320 ×. It was later called Winnecke 4. Finally, in 1966, the American amateur John Mallas revealed that Winnecke's pair is identical with M 40.[290] The no longer missing Messier object and the open cluster NGC 189 in Cassiopeia were the only non-stellar objects of Caroline, which were never observed by her brother.[291]

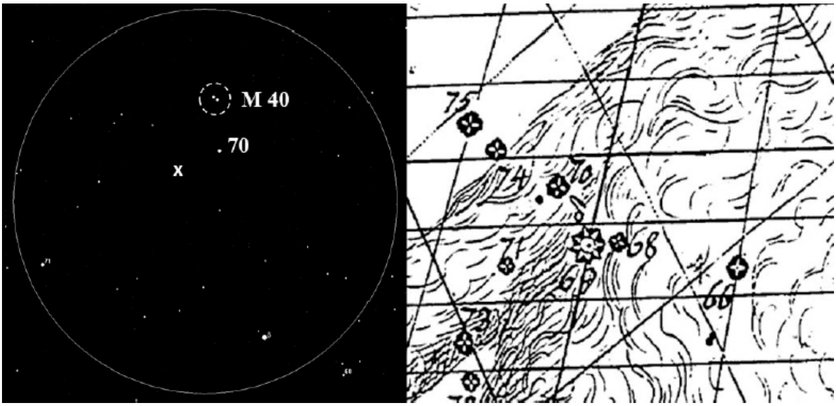


Figure 1-53: Caroline's observation of the star pair M 40 near δ UMa. It was incorrectly entered by her in the *Atlas Coelestis* (dot near 70 UMa), marked 'x' in the 2.2° field of view of the small sweeper.

There are seven observations, which cannot be identified. The first two 'objects' are included in Caroline's table. On 13 October 1782, she noted: "ε Auriga or near it is nebulous" (no. 17: "is marked not yet seen"). There is no object around the 4.7 mag star. The nearest candidate is the open cluster M 36, but it was observed immediately before in that night. On 1 December, she wrote: "1h 40' 28" AR & 13° south Declination; are 3, 4, 5 or more small obscure stars, which I can not help thinking make a nebulous appearance." (no. 18: "not to be found"). The place is 1.5° southeast of ζ Cet. Why is the right ascension so precise? William was not involved ("the King [George III] came to see my 20ft telescope and other instruments").

The next obscure object appeared on 30 July 1783: "In the neck of Equuleus or head of Aquarius, there is a rich spot; near 3, 4, 7 Equulei. Mess. has it not." In the *Atlas Coelestis*, there are three stars

in the ‘neck’, but they already belong to Pegasus (3 & 4 Equ are 8° west, above the ‘head’). In the region, we only find the 13.5 mag galaxy NGC 7102, which is too faint. Another ‘object’ was found on 24 August 1783: “Between γ & δ Equulei a rich spot.” There is nothing but a few asterisms at this place. M 15 in Pegasus was observed next, 5° northeast.

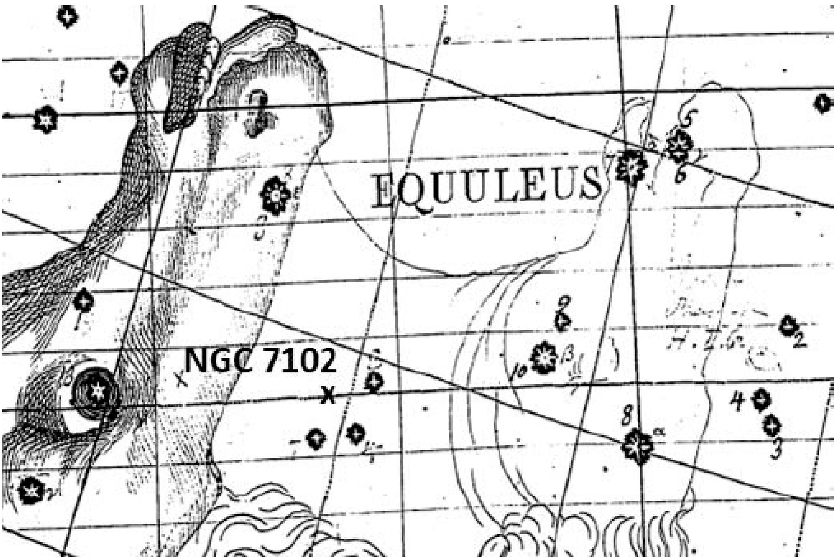


Figure 1-54: Caroline’s obscure ‘rich spot’ near the neck of Equuleus on the *Atlas Coelestis*. The galaxy NGC 7102 near ‘3, 4, 7 Equulei’ was too faint for her small sweeper.

On 18 August 1789, Caroline wrote: “20^h 5' Sid. Time [10:22 pm]. I suspect the object in the figure [sketch] to be a comet.” And 1.5 hours later she noted: “I do not perceive any change in its situation; but there is a very strong Aurora borealis, and the weather hazy; so that I can hardly see the object any longer.” The next night brought no change: “The object I saw last night is fixed. It is none of the Nebulae of the Coniss. des temps, therefore I suppose it to be one of my brother’s, a great number have been discovered by him in that neighbourhood, cloudy.” No doubt Caroline has seen a nebula, but no position is given. Inspecting the area about the meridian at the given time for nebulous objects (globular cluster, planetary) there are no reasonable candidates matching the stars in the field of view.

On 30 March 1793, Caroline wrote: "I saw a patch of very small stars, near the star which is marked κ in the following claw of Cancer (in Harrisses map). I believe the object is new." This might be the open cluster M 67. Caroline had seen it only once, on 26 March 1783, and made a sketch (referring to α Cnc, a bit nearer than κ).

We have seen that Caroline was a true competitor of William in the first years at Datchet (Figure 1-55). Even after the start of laborious sweep campaign, which she assisted William, her observations were continued. The final one was made on 31 January 1836, watching Comet Halley with the naked eye.

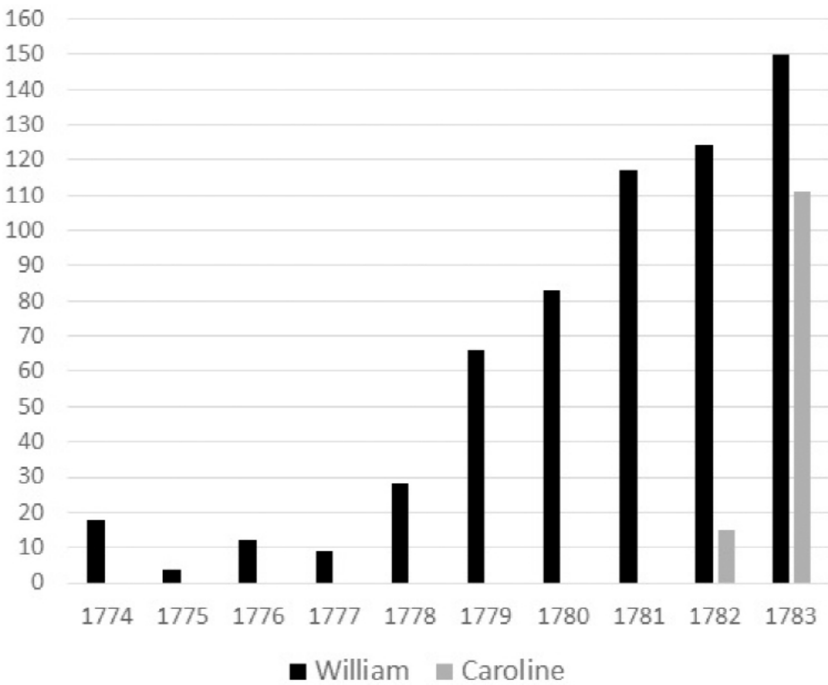


Figure 1-55: Observations made between 1774 and 1783 by William and Caroline before the first sweep.

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1 When using the name Herschel, it always refers to William. Caroline and John Herschel are simply called by their first names. In case of possible confusion, 'William' is used explicitly. For Herschel biographies, see Arago (1842), Holden (1881), Clerke (1895), Sime (1900), Ball (1912),

MacPherson (1919), Lubbock (1933), Sidgwick (1953), Buttmann (1961), Armitage (1962), Millmann (1980), Hamel (1988), Gärtner (1996). For a scientific biography: see Dreyer (1912a: xiii–lxiv). For the German origin of Herschel and his siblings in Hanover, see Hoskin (2007). The English historian Michael Hoskin (*1930) has been the leading researcher on the subject since the 1950s; for his first contribution, see Hoskin (1959). Further material is still in the possession of the current Herschel family, managed by the late John Herschel-Shorland (1935–2017); see Anon (2018) for an obituary. Herschel family documents are also archived at the *Harry Ransom Center* of the University of Texas, Austin, and Harvard's *Houghton Library*. For bibliographical data on the astronomers, mentioned in this book, see Dick, Brüggenthies (2005).

2 William lived in Bath starting 9 December 1766; his former home was Halifax. Caroline wrote two autobiographies in Hanover; see Hoskin (2003a). For the Herschel partnership, see Hoskin (2003b). For Caroline's life, see Herschel Mrs. J. (1876), Lubbock (1933), Hoskin (2003a, 2013, 2014b), Swain (2014), Winterburn (2017).

3 There was an earthquake at Bath on 8 September 1775 (RAS C.3/1.1: 52).

4 Among them was William Watson Jr (1744–1825), who was shown the Moon in late December 1779; Herschel Mrs. J. (1876: 42). The English physician and naturalist introduced Herschel to the short-lived *Bath Philosophical Society* and became a long-time friend. Later the Fellow of the *Royal Society* invited him to communicate his observational results to this body.

5 The *Herschel Museum of Astronomy* is located at the site since 1981 (opened 200 years after William and Caroline lived there). The nice museum is supported by the *Herschel Society*, founded 1977 in Bath.

6 RAS W.5/12.1: 2.

7 RAS W.2/1.1.

8 In this book, the standard abbreviations for the constellations are used.

9 For Herschel's other three sketches of M 42 see Table 3-14.

10 The trio was discovered by Huygens in 1656.

11 Herschel generally uses the terms 'larger' and 'smaller' for brighter and fainter stars.

12 Mizar has four components. Herschel catalogued the double star as III 2 and observed it 18 times between 117 and 1802.

13 RAS W.7/8: 20. This designation refers to the Herschel Archive of the *Royal Astronomical Society* (RAS), London, ordered by Bennett (1978). It contains a large number of original documents by William (W), Caroline (C) and John Herschel (J), available on DVD.

14 RAS W.7/8: 30.

15 Herschel probably bought the second edition of Ferguson's popular book, published 1757 (it had 17 editions). The mentioned 'astronomical tables' could be Ferguson's *Astronomical Tables and Precepts for Calculating the*

true Times of New and Full Moons (1763) or his *Tables and Tracts for Several Arts and Sciences* (1767).

16 A mix of 71% copper with 29% tin yielded the best optical results. Herschel's work on mirrors and telescopes is written down in his four-volume series 'Experiments on the construction of specula', RAS W.5/12.1–4. The 2160 entries cover a period of 45 years, from spring 1773 until the end of 1818. On his telescope making, see also: Tabb (2010).

17 Lubbock (1933: 65). All quotes are presented as they are written, i.e. not correcting errors; occasionally, 'sic' or a comment is added in brackets.

18 Values in feet give the focal length of a lens or mirror. Since there was no manufacturing optician in Bath, Herschel got the lenses for his small refractors from London.

19 Smith (1738: 347).

20 Halley (1714–16), Sawyer-Hogg (1947). Edmond Halley (1656–1742), second Astronomer Royal at Greenwich and discoverer of the globular clusters M 13 in Hercules and ω Centauri ('M' refers to the *Messier Catalogue*).

21 Christiaan Huygens (1629–1695), Dutch astronomer and physicist.

22 Dollfus (2004).

23 This term covers all objects beyond the Solar System, like stars, star clusters, nebulae and galaxies.

24 Ferguson (1756: 384).

25 Claudius Ptolemy (87–165), Greek astronomer, working in Alexandria. He discovered the open cluster M 7 in Scorpius.

26 The naked eye easily separates the stars (distance 13').

27 John Flamsteed (1646–1719), first Astronomer Royal at Greenwich. He discovered the open cluster NGC 2244 in Monoceros.

28 Giovanni Domenico Cassini (1625–1712), Italian astronomer (M 50 was his only find).

29 Ferguson (1756: 379).

30 Ferguson (1756: 380). The details can be found in Steinicke (2014d).

31 Flamsteed (1725, 1729). The first volumes contain the observational data of 1675–1689 and 1689–1720, respectively.

32 Senex (1721, 1728); John Senex (1678–1740) was an English cartographer and publisher.

33 Johann Bayer (1572–1625), German astronomer and maker of the *Uranometria* star atlas; Bayer (1603).

34 Joseph Harris (1702/03–1764) was an occasional astronomer; see Griffith (2012). He observed, for instance, the Venus transit in 1761.

35 Not all constellations in the *British Catalogue* show Bayer letters. The exceptions are Camelopardalis, Canes Venatici, Lacerta, Leo Minor, Lynx, Monoceros, Sextans and Vulpecula. These are later creations by the Polish astronomer Johannes Hevelius (1564–1617).

36 RAS W.7/8: 31.
37 Following Herschel, we simply call both maps ‘Harris maps’ here.
38 For the nebulae and star clusters found before Herschel, see Steinicke (2010a: chapter 2.1), Hoskin (2008).
39 A reprint of the first edition (1729) appeared in 1753. There is also a French edition of 1771, made by the French instrument maker Jean Fortin (1750–1831); it has a more manageable format of about ⅓ the original size. A facsimile of the ‘Flamsteed-Fortin atlas’ was published in 2017 by Albireo Verlag, Köln.
40 The *British Catalogue* lists two entries as ‘Neb’: 33 And = M 31 and 55 And. Both are shown as stars in the *Atlas Coelestis*. The curious case of 55 And is treated in Steinicke (2010a: Chapter 6.14.6).
41 Herschel W. (1795a). Many more observations of the Sun would follow until 4 July 1819. About Herschel’s heat problem when observing the sun, see King (1979: 149).
42 The English amateur astronomer and Royal Navy Admiral William Henry Smyth (1788–1865) later claimed that “the illustrious Sir William Herschel lost an eye in this service”; Smyth (1844, Vol. I, 87). This is not confirmed and, if at all, could have been at most a transient condition. Later, John invented an optical device using prisms, known as the ‘Herschel wedge’, to observe the Sun safely.
43 At the end of *Journal No. 2*, we find a remark by William, added on 24 February 1803: “I wrote with pen and ink, exactly upon the pencil strokes, all those observations which had been written with a pencil, when they were made.” (RAS W.2/1.2).
44 The *Review* series was continued in 1792 with No. 5; it ended in 1818 with No. 8 (see Table 3-12).
45 RAS W.2/1.1: 25.
46 Lubbock (1933: 68).
47 Herschel W. (1783c: 249).
48 RAS W.4/1.1: 1.
49 Castor has six components. Herschel listed it as II 1; the star was observed 36 times from 1778 to 1803 (RAS W.2/5.1).
50 Benedetto Castelli (1578–1643), Italian mathematician; Robert Hooke (1635–1703), English scientist and curator of experiments of the *Royal Society*; James Bradley (1692–1762), 3rd Astronomer Royal. For early double star astronomy see Lewis (1893).
51 RAS W.4/1.1: 4.
52 Galileo Galilei (1564–1662), Italian scientist and founder of ‘astrophysics’; see Chapman (2014).
53 Nevil Maskelyne (1732–1811), 5th Astronomer Royal at Greenwich. At the same time, Herschel was introduced to Thomas Hornsby (1733–1810), Savilian Professor of Astronomy at Oxford University.
54 RAS W.2/1.1: 50.

55 Herschel W. (1782a). The renowned *Philosophical Transactions of the Royal Society* was Herschel's main journal for publication. Altogether 69 papers of him appeared between 1780 and 1818; see Dreyer (1912a, b).
56 Lubbock (1933: 109).
57 Herschel was not aware of Mitchell's paper. John Mitchell (1724–1793) was an English natural philosopher and clergyman. See Hoskin (2012a: 13–20), Hirshfeld (2001: 171–191), Hutton (2006).
58 The 'small 20-ft' got a larger brother in 1783, a 20-ft Newtonian with 18.7 inches aperture. Though the latter is sometimes called 'large 20-ft', we omit 'large' if no confusion is to be feared.
59 In May 1773, Herschel had built a 4-ft refractor of the 'Huygenian construction'. This pole stand was later used for the 10-ft reflector; see King (1979: 123).
60 RAS W.5/12.1: 56.
61 This orientation is affirmed by Herschel, when describing his early observations of Messier objects with the small 20-ft in his 1784 paper: "I have examined them with a careful scrutiny of various powers and light, and generally in the meridian." See Herschel W. (1784b: 440).
62 RAS W.5/5.
63 The fourth star was discovered on 20 March 1673 by the French astronomer Jean Picard (1620–1682) in Paris. Huygens also saw the four stars on 8 January 1684.
64 Herschel W. (1782b: 129).
65 See Table 3-14 for all observations of the Orion Nebula.
66 RAS W.2/2.1.
67 RAS W.4/1.1: 42, RAS W.4/1.2: 124. The 'constellation' is sometimes called 'Fluvius Aquarii' (a part of Aquarius); see Allen (1963: 51).
68 RAS W.2/1.1: 108, RAS W.4/1.1: 8.
69 Here Giovanni Domenico Cassini is meant, who had published a map in 1708, titled 'Figure des Pleiades avec le passage de la Lune'. Herschel again observed the star cluster on 30 August 1780: "η [Alcyone] has four stars near that all come within about 4 Minutes."
70 A drawing was made by William Watson Jr (RAS W.5/5); see title page of this chapter.
71 Polaris A = 2.0 mag, B = 9.0 mag, Distance 18"; in 1929, it was detected that A itself is a very close pair (0.17").
72 The English naturalist Joseph Banks (1743–1820), President of the *Royal Society* (see Figure 2-120), and the Astronomer Royal Nevil Maskelyne became good friends of the Herschels.
73 Alexander Aubert (1730–1805), ambitious English amateur astronomer and businessman, who ran a notable private observatory at Highbury House (Loampit Hill, Deptford), about a mile southwest of Greenwich Observatory; see Lubbock (1933: 108). John Dolland (1706–1761) was the leading English optician and instrument maker.

74 RAS W.7/8: 33.
75 Herschel W. (1783c: 249).
76 Herschel's 7-ft was the forerunner of the modern Dobsonian reflector. It had a ¾-inch, single eye lens finder.
77 Dreyer (1912a: 9).
78 RAS W.5/12.1: 48–58, Maurer (2013).
79 RAS W.4/1.3: 356.
80 Mira is catalogued as VI 1 in the first catalogue of double stars; Herschel W. (1782b). However, a wrong date is given (20 October 1777).
81 RAS W.2/1.2: last page.
82 RAS C.3/1.1: 12.
83 RAS W.2/1.2: last page.
84 Patrick Brydone (1736–1818), Scottish traveller and author.
85 RAS W.4/1.1: 65. The uncatalogued star near μ Dra (5.6 mag) is HR 6237 (4.8 mag), listed in the *Yale Bright Star Catalogue*.
86 This is the Flamsteed star 1 Gem (4.2 mag), located near the triple border of Gemini, Taurus and Orion.
87 One can experience a copy of Herschel's observation on 13 March 2033. After three revolutions around the sun, the planet returns to its discovery place in 1781; the position will be only 20' west. Interestingly, on 23 January 1930, Pluto was found 43' west of δ Gem, which is 18° west of H Geminorum.
88 RAS W.4/1.1: 91–95.
89 RAS W.2/1.2: 23.
90 RAS W.4/1.1: 92–93.
91 Herschel W. (1781). The term 'read to the *Royal Society*' is commonly used, meaning that the text was presented at an ordinary Society meeting by a Fellow. This was done by William Watson Jr before Herschel got this status in late 1781.
92 For the implication of Herschel's discovery and the reaction of contemporary astronomers see Schaffer (1981).
93 Lubbock (1933: 81).
94 Herschel W. (1782a). At the 7-ft, this power was tried on Vega, Polaris and γ Leo.
95 Lubbock (1933: 99). Bedlam is the nickname of a notorious psychiatric hospital in London.
96 Lubbock (1933: 101), Herschel W. (1782d).
97 Lubbock (1933: 104).
98 Bode (1781); the translation is due to Holden (1881: 55), who added the version in brackets. The German astronomer Johann Elert Bode (1747–1826) was Director of Berlin Observatory and editor of the *Berliner Jahrbuch* (Figure 2-99).
99 Herschel noted about the eye-piece, giving 227× at the 7-ft reflector: "my field of view is 4' 27".968" (RAS W.4/1.1: 94).

100 In Herschel's catalogues the maximum distance between the reference star (Bayer, Flamsteed) and a double star is 4.4° (mean 1.1°). Thus, he must have searched the area around H Geminorum thoroughly with his small field of view.

101 Lubbock (1933: 123). Bode's letter, in his poorly legible German handwriting, is archived in RAS W.1/13: B.104.

102 Holden (1881: 56).

103 Later Herschel created the review 'Observations on the Georgian Planet and its Satellites', collecting all observations from 13 March 1781 to 27 January 1792 (RAS W.3/1.10).

104 RAS W.2/1.3: 41.

105 Pierre Méchain (1744–1804) was a French astronomer and surveyor. He found 26 Messier objects and one NGC object.

106 The English amateur astronomer Edward Pigott (1753–1825), known for his observation of variable stars, saw the comet on 19 November in Cetus.

107 George III (1738–1820), King of Great Britain and Ireland.

108 Lubbock (1933: 122).

109 To impress the King, it was published in the *Philosophical Transactions*: Herschel W. (1783a). The name 'the Georgian' was used until 1847 in the British *Nautical Almanac*.

110 Bode (1784). On the naming of Uranus see Gingerich (1958).

111 Tobias Mayer (1723–1762), German astronomer of Göttingen Observatory. He should not be confused with the double star observer Christian Mayer (Mannheim). For Uranus as a 'star' see: Bode (1784), Wollaston (1789), Baily (1831).

112 RAS W.4/1.2: 181.

113 The Finnish-Swedish astronomer and mathematician Anders Lexell (1740–1784) visited England at that time; see Stén (2018). The orbital period of Uranus was later measured to be 84 years.

114 RAS W.2/1.4: 25. Herschel determined the diameter of Uranus several times with a micrometer, getting 3" to 5"; Herschel W. (1783b).

115 RAS W.1/1: 57–59. Joseph-Jérôme de Lalande (1732-1807), French astronomer, mathematician and author of the large star catalogue *Histoire Céleste Française*; Lalande (1801).

116 Charles Hutton (1737–1823) was a mathematics professor at the Royal Military Academy at Woolwich and editor of the *European Magazine*; see Lubbock (1933: 78).

117 There were 10 more conjunctions, though with distances of 3.3° to 6.4°. Alas, Neptune did not appear in a sweep, where the chance of a discovery was significantly higher.

118 The star was found to be a close double on 21 January 1780 (second review); Neptune was 3.7° west then.

119 The pair, listed as III 53 in the first double star catalogue, is 2.5°

southeast of γ Vir (Herschel W. (1782b).

120 For the eye-piece with 460×, Herschel gives no field of view. However, from a note about the "double treble star σ Orionis" it can be estimated: "my 227 and 460 takes them all in the field together"; see RAS W.4/1.2: 133. The maximum separation between the six components is about 3.6'.

121 For the start and end dates see RAS C.3/1.1: 12 and RAS W.4/1.5: 440, respectively. Dreyer is incorrect in writing that Herschel started the third review "at the end of December 1781" and that it "was closed in January 1784"; see Dreyer (1912a: xxxix). The latter date refers to a double star encountered in sweep 99 on 23 January 1784, subsequently catalogued as III 114. All further double stars got a new designation (N1 to N145).

122 Herschel W. (1783c: 249).

123 Herschel got the 3rd edition, published 1781 by the bookseller C. Nourse of the Strand, London; see Ridpath (2015).

124 RAS W.4/1.2: 109.

125 RAS W.4/1.2: 140.

126 In this book, right ascension is abbreviated AR ('ascensio recta'). Like time, it is measured in hours (0–24, or sometimes 0–XXIV). In older works, like the *British Catalogue*, AR is often measured in degrees (0–360°); the conversion factor is 15. Note that the abbreviation RA is also used in the literature.

127 Steinicke (2014d).

128 Herschel C. (1789); Baily (1835). Francis Baily (1774–1844), English astronomer and founding member of the *Astronomical Society of London*. His book gives a comprehensive presentation of Flamsteed's life and work. On 25 March 1827, Baily discovered the 12.7 mag galaxy NGC 3457 (h 793) in Leo while experiencing a sweep at Slough with the 18¼-inch reflector, supervised by John.

129 It is preserved in the Herschel Archive of the *Royal Astronomical Society* (RAS C.2/10).

130 Herschel Mrs. J. (1876: 45).

131 Herschel W. (1785b: 43).

132 Herschel W. (1796: 181). The author did the same in his own copy of the *British Catalogue*, soon finding out that there are differences in the numbering when compared to 'modern' Flamsteed numbers, used in star maps or planetarium software. This is due to later revisions, like those of Baily (1835) or the *Uranometria nova* (1843) of Friedrich Argelander (1799–1875), German astronomer and Director of Bonn Observatory.

133 RAS W.2/2.4.

134 James Lind (1736–1812) is a Scottish physician. He was, fortunately, present at Caroline's accident on 31 December 1783, providing her medical care.

135 The identity of 'Mr. Hawkings' is unknown.

136 RAS W.2/1.3: 36. The reference to "last year" is obviously wrong;

Uranus was discovered in March of that same year.
137 De novis in coelo sidereo phaenomenis in miris stellarum fixarum comitibus, Mayer (1779). Christian Mayer (1719–1783), German astronomer and Director of Mannheim Observatory. For his catalogue see 1.5.1.
138 Messier (1780); the appendix is on page 408. Charles Messier (1730–1817) was a French astronomer, observing at Hôtel de Cluny, Paris, with small telescopes. He discovered 13 comets and 41 non-stellar objects (listed in his catalogue).
139 William's younger brother Alexander Herschel (1745–1821) lived in Bath. He was very technically gifted and made several telescopes and devices; see Millmann (1980: Part III); Hoskin (2004).
140 The focal length of the single-lensed eye-piece must have been 0.3 mm. The high magnifications are described in Herschel W. (1782d). In 1924, Steavenson examined 48 of Herschel's eye-pieces. William Herbert Steavenson (1894–1975) was an English amateur astronomer and friend of the Herschel family.
141 Stephen Charles Demainbray (1710–1782) was Director of the King's Kew Gardens Observatory; see Mcdonald (2018). In his early sweeps, Herschel used one of his clocks, but was not satisfied; see RAS W.2/1.7: 20. On 1 March 1791, his son Stephen George Demainbray (1760–1854), who became successor of his father in 1782, visited Slough to see Uranus.
142 RAS W.4/1.3: 214. 'Dollond' is John Dolland. 'Short's reflector' is due to the Scottish mathematician and telescope maker James Short (1710–1768).
143 Herschel Mrs. J. (1876: 118).
144 Datchet, a mile east of the castle, became a popular spot for visits from the Royals and their court. On 31 June 1783 Prince William (1765–1837), third son of King George III was a guest; he viewed Jupiter and Saturn with the 10-ft. And on 17 July, Herschel wrote: "His Royal Highness expressed much satisfaction on the method of managing my telescopes."
145 RAS W.7/8: 36.
146 On 23 August 1780, the small 20-ft was used, seeing ε Boo at 300× "very fine and distinct".
147 See the section 'Moisture in the air' in Herschel W. (1803a: 218).
148 Herschel Mrs. J. (1876: 139).
149 Lubbock (1933: 116).
150 The former double star is III 54; the latter IV 60 (SAO 14654), with components of 7.7 and 12.0 mag, 28" distant. See Table 1-9 for Herschel's double star designations.
151 The others are: Anthony Shepherd (1721–1796), British astronomer, Plumian Professor at Cambridge; John Playfair (1748–1819), Scottish professor of natural philosophy at Edinburgh; John Arnold (1736–1799),

British watchmaker.
152 See also Steinicke (2021a).
153 RAS W.4/14.
154 Herschel W. (1782b).
155 Compare Herschel W. (1782a: Fig. 12) and Herschel W. (1782b: 114).
156 On 18 January 1783, Herschel introduced a further class for β CMa (Mirzam): "The 7th class of double stars which I shall now take notice of are such as can be measured with a high power that is not exceeding 3 or 4' minutes of distance and consisting of very unequal stars the large one of which is at least the 3rd magnitude." (RAS W.4/1.4: 312). Class VII does not appear in the catalogues. β CMa (VII 1) has a 10th mag optical companion about 3' north.
157 Dreyer (1912a: 73). John Louis Emil Dreyer (1852–1926), Danish-born astronomer working at Birr Castle before he became Director of Armagh Observatory (see Figure 6-14); Steinicke (2010a). He discovered 15 NGC- and one IC object.
158 Caroline made a copy, RAS W.4/7.
159 Herschel W. (1782b: 161).
160 About British university observatories, see Hutchins (2008). For the Victorian amateur scene, see Chapman (1998).
161 For instance, II 24, VI 12 and VI 56 of the manuscript are III 22, V 14 and V 37, respectively, in the paper.
162 RAS W.2/15.
163 Herschel W. (1785b).
164 Herschel W. (1782c), Clerke (1895: 103); see also Hope (2019). Herschel's micrometers were mainly constructed by the English instrument maker Edward Nairne (1726–1806).
165 RAS W.4/33.4 shows star-hopping trails for 17 planetary nebulae and 10 Messier objects. Finding an object by coordinates was the domain of the equatorial refractor, equipped with setting circles.
166 However, Herschel did not count the Lynx stars correctly in the *British Catalogue*: his stars 39 and 44 are actually 40 and 43 (the former is α Lyn). This was noticed by Caroline (see Figure 2-98). The double star I 32 is located in Leo Minor.
167 Register od Double Stars, RAS W.2/5.1–4.
168 RAS C.3/1.2: 28.
169 It was formulated by Isaac Newton (1624–1727) in the *Principia* of 1687. Herschel probably purchased the version, translated by the English engraver Andrew Motte (1696–1734), published in 1729 (M. Hoskin, private communication).
170 RAS W.2/1.4: 32. Castor was observed 49 times between 8 April 1778 and 31 May 1803. In 1827 it was detected that the double star ξ UMa (found as I 2 on 2 May 1780) shows an elliptical orbit with a period of 58¼ years.

171 Herschel W. (1803b: 340), Herschel W. (1804).

172 Herschel W. (1783c: 257). The main subject was the determination of the direction of the solar motion (apex). Based on roper motion data of Maskelyne and Lalande (12 stars in total), Herschel revealed that the Sun moves towards the 4.4 mag star λ Her. This was later confirmed. See Hoskin (2012a: 22).

173 RAS W.2/1.4: 32.

174 The chart was created, like others in this book, with *Guide 9.1* (the software includes the author's revised NGC/IC).

175 Charles Blagden (1748–1820), British physician and Secretary of the *Royal Society*, often visited the Herschels; see Figure 2-120.

176 'U stars' are listed in Caroline's 'Catalogue of the stars which have been observed by Wm. Herschel in a series of Sweeps; brought into zones of N.P. Distance and order of AR. for the year 1800, by applying the variation given with each respective star in Wollaston's or Bode's Catalogues' (RAS C.3/2.3). The last column ('Gen. No.') gives the U number.

177 RAS C.3/1.1: 29. The index was begun in June 1787; Herschel Mrs. J. (1876: 74).

178 This was the only observation of Mira with the 18.7-inchreflector.

179 Argelander (1869: 320–326).

180 RAS W.2/1.3: 40.

181 RAS W.4/1.2: 171.

182 Steinicke (2011a).

183 Steinicke (2011, 2015). Julius Schmidt (1825–1884), German astronomer and Director of Athens Observatory. He discovered 16 NGC objects. Friedrich Bessel (1784–1846), German astronomer, mathematician, physicist and geodesist. He was Director of Königsberg Observatory and measured the first reliable parallax of a star (61 Cyg) in 1838.

184 The Irish amateur astronomer John Birmingham (1816–1884) published a catalogue of 658 red stars in 1876.

185 The variable star was known to Herschel by Ferguson's *Astronomy*; see Ferguson (1756: 335).

186 Mira is the subject of Herschel's first paper in the *Philosophical Transactions*; Herschel (1780). It covers the period from 20 Jan. 1777 to 23 Dec. 1780; see also: Dreyer (1912a: civ–cv). Mira is also listed as double star VI 1; Herschel W. (1782b).

187 Tycho Brahe (1546–1601), Danish astronomer, Cornelius Gemma (1535–1577), Belgian astronomer; David Fabricius (1564–1617), German astronomer, Willem Blaeu (1571–1638), Dutch cartographer; Johannes Kepler (1571–1630), German mathematician and astronomer; Gottfried Kirch (1639–1710), German astronomer, discoverer of M 5 in Serpens and M 11 in Scutum.

188 Ferguson (1756: 385); see also: Hoskin (1982). In 1884, the American astronomer Edward Pickering (1848–1919), Director of the Harvard College Observatory, analysed Herschel's variable star observations; see Pickering (1884b). He discovered 15 NGC- and two IC objects.
189 See also: RAS C.4/3: 38, Dreyer (1918b).
190 This remarkable Cepheid had shown a variability between 1.86 and 2.13 mag, which currently has stopped.
191 John Goodricke (1764–1786), mute-deaf English amateur astronomer and variable star observer. He was a good friend of Edward Pigott; Hoskin (1982). For early variable star catalogues see Zsoldos (1994).
192 This reflector should not be confused with the 7-ft, equipped with a 6.2-inch mirror, used for Uranus in 1781.
193 Mitchell (1767).
194 M 7, M 11, M 24, M 37, M 40 and M 56 share this fate (Table 5-23). However, all were viewed with other telescopes, except M 40, which is of no importance – the object is only a pair of stars.
195 RAS W.2/1.2: 4.
196 Messier (1774).
197 Messier (1780).
198 RAS W.4/1.3: 223, RAS W.4/1.4: 378.
199 The observation was not made in a sweep (γ Lyr was also seen). On 10 July, M 57 passed the field of view in sweep 234.
200 Herschel W. (1785c: 263). The figure was copied by Bode (without permission); see Bode (1785b: 242).
201 This is the Swiss geologist and meteorologist Jean-André Deluc (1727–1817). He moved to England in 1773, where he was appointed reader to Queen Sophie Charlotte (1744–1818).
202 RAS W.4/1.3: 217 (note added to record of 5 August 1782).
203 M 5 was discovered by the German astronomer Gottfried Kirch in 1702.
204 Messier's coordinates are for the equinox of the observing date (e.g. M 1 for 1758). The *Atlas Coelestis* refers to the equinox 1690. So, there is a slight difference in the positions. There is no hint that Caroline precessed the positions. Of course, due to the scale of the atlas, this is of little importance.
205 RAS W.2/1.5: 34.
206 RAS C.1/1.1: 4.
207 Meanwhile (on 8 December 1782), the small 20-ft got a new mirror; Herschel "found it to bear a magnifying power of 2457", but on 1 January the mirror "cracked with the frost" and on 1 March "another new 20 feet [mirror] was tried" (RAS W.7/8: 36). On the 8th, Herschel wrote: "my telescope is the best in the world" (RAS W.2/1.5: 41).
208 RAS W.4/1.4: 338. The objects, mentioned below, are all in this document (*Fixt Stars No. 4*); they can be found by the given date.
209 M 69 and M 70 are only mentioned in the appendix of the second

catalogue (both are globular clusters in Sagittarius). William did not observe them in that period.

210 M 53 was sketched on 14 March 1784 in sweep 170 (Figure 2-44).

211 John Bevis (1695–1771) was an English doctor and astronomer. He is the author of the large star atlas *Uranographia Britannica*, finished in 1750 but not published. In 1785, 51 of its charts appeared in bound form as *Atlas Celeste* by an unknown publisher (with no hint to its author); see Kilburn et al. (2003).

212 The name goes back to 1840, when Romney Robinson (1792–1882), Director of Armagh Observatory, commented a drawing of M 1 made by Lord Rosse: "It is ragged, bifurcated at the top, and has streamers running out like claws in every direction." See Steinicke (2018b).

213 Messier (1781). The positions are for each discovery date. The inconsistent equinox has caused problems among observers. It was Auwers who first reduced the positions to a common equinox (1830); see 6.3.

214 Giovanni Hodierna (1597–1660), Italian priest and astronomer; he discovered eight Messier- and four NGC objects.

215 Herschel saw both objects eventually with the 18.7-inchreflector: M 98 in sweep 73 (30 December 1783), M 99 in sweep 187 (8 April 1784).

216 RAS C.1/1.4: 15.

217 The bipolar planetary nebula known as the Little Dumbbell (due to its similarity to the Dumbbell Nebula M 27) is among the faintest Messier objects. It was seen not until 12 November 1787 in sweep 780. Herschel perceived a double nebula: one component was identified with M 76, the other was catalogued as a new object (I 193). A third observation was made on 18 October 1805 with the 7-ft.

218 This is the first object, taken from Messier's final catalogue, received in May 1783.

219 M 6, known as the Butterfly Cluster, is only 2.5° more north.

220 Herschel never travelled further south than Paris, but his son John would eventually reach Cape Town; see Hoskin (2003c).

221 The observation of all 103 M-numbers within a single night (in spring) is called 'Messier-Marathon'. This task needs a perfect south view, to catch M 6 and M 7 from central Europe.

222 M 24 is the only Messier object listed in Dreyer's *Index Catalogue* (IC 4715). The region in Sagittarius was observed in sweep 230 (18 June 1784). Some gages were made here, giving large numbers of stars. However, M 24 is not mentioned. The first to describe the extended object was John in a sweep at Slough (h 2004); h-numbers refer to the *Slough Catalogue*, Herschel J. (1833a).

223 It is strange that on 11 November 1784, when Herschel saw M 33 for the first time with the 18.7-inch(sweep 266), the object was not identified as such. Consequently, it got a catalogue number: V 17 ('large nebulae').

224 Bode discovered four Messier objects: M 53, M 81, M 82 and M 92, using a small refractor.
225 RAS W.4/1.5: 406.
226 Steinicke (2012d).
227 This is due to a handwritten note in Messier's personal copy of the final catalogue.
228 Steinicke (2019c).
229 Patrick Wilson (1743–1811) was a Scottish astronomer and Professor at Glasgow University. He founded the theory that sunspots are openings in their atmosphere, showing the Sun's true surface. This was adopted by Herschel.
230 Two mirrors were cast on 28 March; RAS W.5/12.1: 61. The first was tried on 23 October. Sometimes the new reflector is called 'large 20-ft'; this term is omitted here.
231 Nicolas-Claude Fabri de Peiresc (1580–1637), French astronomer, found M 42; As-Sufi (903–986), Persian astronomer; found M 31 and IC 2391 in Vela; Aratos (315–245 B.C.), Greek philosopher; Aristoteles (384–322 B.C.), Greek philosopher, found M 41; Jean-Dominique Maraldi (1709–1788), Italian astronomer, found M 2 and M 15; Phillippe de Chéseaux (1718–1751), Swiss astronomer, found six M- and two NGC objects; Gottfried Koehler (1745–1801), German astronomer, found six Messier objects; Abraham Ihle (1627–1699), German astronomer, found M 22; Nicolas-Louis de Lacaille (1713–1762), French astronomer, found 23 NGC- and three IC objects; Guillaume Le Gentil (1725–1792), French astronomer, found M 32; the French geophysicist and astronomer Jean Jacques de Mairan (1678–1771) found M 43.
232 For Herschel's telescopes see Steavenson (1924, 1925). Being a friend of the Herschel family, Steavenson could study their collection of William's instruments. The mirrors were also tested by Hysom (1996). Concerning Herschel's telescopes, see also: Mauer (1971, 1996), Bennett (1976a), Gargano (2012).
233 Herschel W. (1784b: 439–442).
234 Before the French revolution, the almanac was named *Connoissance des Temps*, then *Connaissance des Temps*; Herschel used both names. The change affects Messier's final catalogue, published in 1798.
235 The open cluster Tr 7 was catalogued in 1930 by the Swiss astronomer Robert Trümpler (1886–1956). He changed his last name to Trumpler in 1915, so the cluster is also called Trumpler 7.
236 Do not confuse Herschel's double star notation (I 10) with that for nebulae and star clusters, found in the sweeps (VIII 25); both designations have the same structure, but very different meanings.
237 Herschel W. (1782a: 84).
238 Ferguson (1756: 384). Flamsteed observed the star ε (7) Per on 19 Dec. 1693, noting "duar[um stellarum] in nebul[a] ad ε praeced[ens]",

meaning “Of the two stars in the nebula near ε, the preceding one.” (translated by Roger Ceragioli).

239 Hipparchus (190–125 BC), Greek astronomer.

240 In later years, Herschel more and more doubted Flamsteed’s brightness values, as given in the *British Catalogue*. This was the reason for his thorough investigation to determine a new stellar brightness scale (see section 3.1).

241 This wrong credit was backed by the English amateur astronomer Kenneth Glyn Jones (1915–1995), founder of the *Webb Deep-Sky Society*; Glyn Jones (1975: 21). In the *British Catalogue*, the three stars 4 (b), 5 (i) and 7 (a) Sgr, observed on 8 June 1691, are called ‘Nebulosæ’, but not 9 Sgr, observed on 23 June 1705 and located near the centre of M 8. However, the original data (Vol. II of the *Historia Coelestis*) are different: b and i are noted as ‘preceding’ the nebula.

242 It is interesting that Messier refers to the “9th star in Sagittarius” which indeed is 9 Sgr. Obviously, he also ‘counted’ the Flamsteed stars in the constellation, albeit not as explicitly as Herschel later did.

243 The strange case of Herschel’s observation of M 8 is further treated in 2.2.6.

244 Only a few sweeps were made in this area at the Ophiuchus/Serpens border.

245 John Hind (1823–1895), was an English astronomer and Superintendent of the *Nautical Almanac*; he is known for the discovery of Hind’s Crimson Star in Lepus (see section 2.3.2). He discovered three NGC objects, among them Hind’s Variable Nebula (NGC 1555) in Taurus; see Steinicke (2010a: chapter 11.4).

246 RAS W.2/1.2: 14.

247 Herschel found NGC 1857 in sweep 619 on 18 October 1786.

248 Compare Caroline’s observation of M 47 in the next section.

249 This is Herschel’s first object appearing in Dreyer’s *Index Catalogue*. There is a total of nine IC objects; seven were found in the sweeps (see Table 3-3). Solon Bailey (1854–1931), American astronomer, working at the Harvard College Observatory. He discovered the reflection nebula IC 1995 in Taurus.

250 Herschel had experienced only two planetaries: M 27 and M 57; see also Steinicke (2007b).

251 22 observations were made of NGC 7009 with various instruments from 1782 to 1810. Only M 42 has more (43).

252 Herschel W. (1785c: 263).

253 For the colour of planetary nebulae in connection with the Herschels, see Steinicke (2007b).

254 The dates are 29 August, 2, 17 & 25 September 1799, 12 October 1805 and 25 September 1810. It is remarkable that Herschel never noticed the 11.5 mag central star. Actually, it is a difficult target, hidden in the bright

nebulous mass.

255 Wilhelm Struve (1793–1864), German astronomer and Director of Dorpat Observatory; he discovered six NGC objects. NGC 7009 is contained in Lalande's *Histoire Céleste* as a star (LL 40765).

256 A viewing angle of 81° means a nearly edge-on orientation of the 'ring'. Lord Rosse is William Parsons, 3rd Earl of Rosse (1800–1867), eminent Irish engineer and astronomer. He discovered two NGC objects at Birr Castle; Steinicke (2014c).

257 M 71 is one of two non-stellar objects seen in the small constellation Sagitta. The other is the star group NGC 6839 (VI 16), found on 18 August 1784 (sweep 252).

258 Is this instrument Caroline's small refractor? It is doubtful, because she used this telescope in that night from 7 to 9 pm, finding the open clusters M 46 in Puppis and NGC 2311 in Monoceros. William confirmed them with his reflectors. Moreover, on 22 December 1782, Caroline mentions an "18 inch acchromatic" (1.5-ft) for sweeping (RAS C.1/1.1: 3). William noted on 7 December 1782 that 118 Tauri was seen with an "18 inch acchromatic of Nairnes". On the 24th we read about an achromatic refractor of 3.5 feet focus: Rigel was observed "with Dollands 3ft Ac". Probably it was used on 4 March 1783 by William for sweeping. Beside Edward Nairne, John Dolland is also mentioned.

259 Herschel Mrs. J. (1876: 52); on Caroline's role see Hoskin (2002).

260 RAS C.1/1.1.

261 Because we do not have William's copy of the Harris maps, it cannot be verified whether Caroline also entered star numbers or Messier objects on them.

262 Herschel Mrs. J. (1876: 54).

263 RAS C.1/1.1: 3.

264 Hoskin (2005a).

265 Hoskin, Warner (1981). Brian Warner (*1939) is an American astronomer, who worked at Cape Town University.

266 Caroline's refractor is stored in the *Historisches Museum*, Hannover.

267 RAS C.1/1.5: 47. Caroline's document (titled 'Index') also contains tables headed 'Rich Spots', 'Comets', 'General Observations' and 'Clusters of Stars & Nebulas of Messier'.

268 RAS C.1/1.1: 1.

269 John Herschel coined this name in the *Slough Catalogue* (h 2070): "The central mass may be compared to a vertebra or a dumbbell."

270 RAS W.2/1.4: 43.

271 RAS C.1/1.1: 5.

272 RAS C.1/1.1: 6.

273 RAS W.2/1.5: 39.

274 In Herschel's second catalogue, the open cluster VII 27 = NGC 2349 is incorrectly credited to Caroline. Obviously, NGC 2311 (VIII 60) is meant;

here she is not mentioned. VII 27 was discovered on 24 February 1786 (sweep 529).

275 Messier's drawings: M 42 is published in Messier (1774: Plate VIII) and M 31 in Messier (1807).

276 Messier (1798). The galaxy was added as M 110 to the *Messier Catalogue* by Glyn Jones in 1966.

277 On 29 August, 27 September and 13 December 1783 and on 7 July 1788, then using the large sweeper.

278 In the notes of Herschel's first published catalogue, V 19 is erroneously credited to Caroline (instead of V 18); this is due to a confusion (see section 2.4.1).

279 NGC 253 is known as the Sculptor Galaxy or Silver Dollar Galaxy (see figure on page 4); Steinicke (2018a).

280 Herschel incorrectly credits Caroline for NGC 381 (VIII 64). The open cluster was found in sweep 774 on 3 November 1787.

281 Hoskin (2005b) favours NGC 659.

282 Steinicke (2013a).

283 RAS W.2/2.6: 39.

284 RAS C.1/1.3: 100.

285 Karl Ludwig Harding (1765–1834), German astronomer, working at Schroeter's private observatory at Lilienthal. He was the discoverer of the third asteroid Juno and the large planetary nebula NGC 7293 in Aquarius (Helix Nebula), found in September 1823 (see Figure 6-5).

286 The elongated nebula is an easy target for a reflector of about 10 inches aperture. It indeed looks like a comet when first viewed; see Steinicke (2015b).

287 Herschel discovered the 13.2 mag galaxy NGC 3104 (IV 48) on 18 March 1787 in sweep 716.

288 Auwers (1862: 69). Arthur Auwers (1838–1915), German astronomer and author of a revision of the Herschel catalogues (see section 6.3). He discovered the galaxy NGC 6503 in Draco.

289 Friedrich Winnecke (1835–1897), German astronomer. He discovered eight NGC objects.

290 John Mallas (1927–1975), American amateur astronomer. Recently the GAIA satellite revealed that M 40 = Winnecke 4 is definitely not a physical pair.

291 On 5 August 1799 Herschel wrote: "No. 40 of neb. of the Con. is not visible in the finder [of the 10-ft reflector]." On 19 April 1789 (sweep 923), he had missed M 40 by only 12', when observing NGC 4290 in Ursa Major.

2. The great sweep campaign

Herschel occasionally encountered new nebulae and star clusters

when searching for double stars. His first find was the open cluster NGC 2232 in Monocerotis on 5 December 1779. Ten more objects were discovered by 23 September 1783, when the star reviews were finished. William was impressed by Caroline's success at finding non-stellar objects. This convinced him that there was much to discover in the virgin field of nebular astronomy.

In the autumn of 1783, Herschel developed the idea of a systematic search which eventually would cover the northern sky and parts of the southern sky visible from the Windsor area. Of course, this would require a suitable method to complete the task in a manageable period of time, and an adequate telescope to discover fainter objects. A Newtonian reflector with 18.7 inches aperture and 20 feet focal length was already operational that time, so the big sweep campaign, to be called just his "fourth review", was about to begin. It would take nearly 20 years and find the immense number of roughly 2500 non-stellar objects that were previously unknown. William was always supported by his talented sister Caroline (Figure 2-1). She did all of the desk work required to handle the flood of observational data with the utmost accuracy.

Figure 2-1: This pretty picture, made in 1896, shows William polishing a mirror, assisted by Caroline – in the living room! Note: The model of the new 20-foot telescope on the cabinet never existed.[292]

This chapter describes the epochal mission in detail. The chronological presentation contains the methodological and instrumental developments, as well as describing a large number of deep-sky objects, although only the important ones are included. Admittedly, the presentation of the observations can sometimes

seem monotonous, but there is no alternative, as it exactly reflects the Herschels nocturnal work. The many figures, showing sketches and modern images of remarkable objects, are sure to bring some relaxation.293

2.1. Starting the sweeps in 1783

2.1.1. A new telescope

Obviously, the former astronomers whose observation led to the *Messier Catalogue*, had missed several objects. Herschel therefore drew up a plan for a comprehensive sky survey with the aid of a superior telescope. The instrument, eventually erected at Datchet in October 1783, was a Newtonian reflector of 20 feet focal length with an 18.7-inch mirror.294 Due to the alt-azimuthal mounting of the instrument, there are some basic celestial angles, essential for observing (Figure 2-2). Their definition and value for the site at Datchet, located at longitude 0.57° east and latitude 51.5° north, are given in Table 2-1. They also apply for the later sites Clay Hall and Slough, all located in the Windsor area (Figure 2-3).

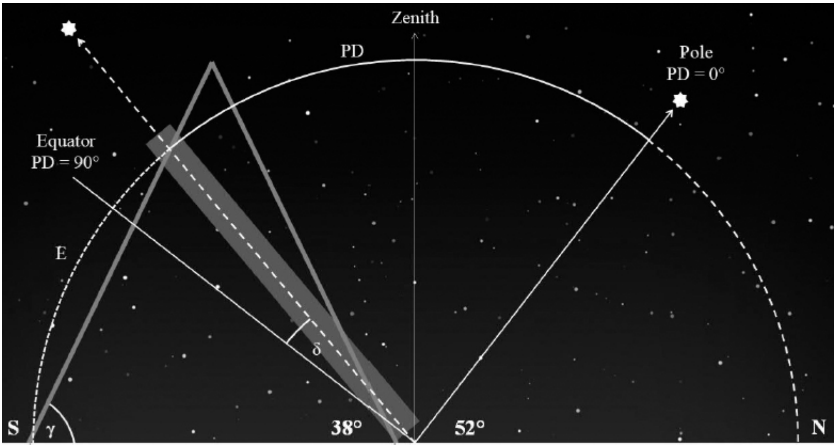


Figure 2-2: Basic celestial angles.

Subject	Symbol	Meaning / value	Range
polar distance	PD	angle between pole and object, PD = 90° - δ	0° to 128.5°
elevation	E	angle between horizon and object	0° to 90°
declination	δ	angle between equator and object, δ = 90° - PD	-38.5° to +90°
quadrant	Q	angle between zenith and object, Q = 90° - E	0° to 90°
azimuth	A	angle between north (0°) and telescope direction	0° to 360° (east = 90°)
Pole	P	latitude of site = 51.5°	
equator	-	E = 90° - P = 38.5°, PD = 90°	
zenith	-	E = 90°, PD = 90° - P = 38.5°	
horizon	-	E = 0°, PD = 128.5°, δ = -38.5°	

Table 2-1: Definition and value of celestial angles, valid for Datchet, Clay Hall or Slough.295

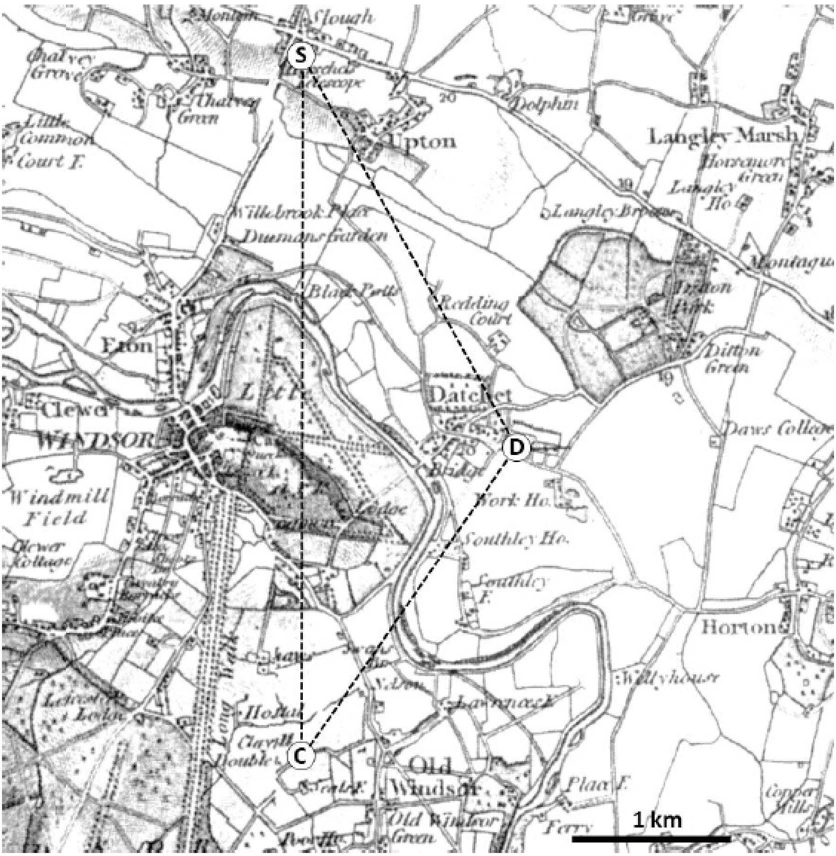


Figure 2-3: Ordnance map of the Windsor area in 1830. Herschel's homes are marked: Datchet (D) 1.5 km west of Windsor Castle, Clay Hall (C) 1.5 km south and Slough 2 km north (S); the dashed triangle connects the three places.296

Herschel's standard reflector had an 18.7-inch metal mirror of 20 feet focal length. It is not to be confused with the 'small 20-ft' of 12 inches aperture, which was suspended from a pole (Figure 1-10). For the new telescope he developed a triangular stand ('Herschel mounting'). Table 2-2 shows the data, Figure 2-4 the construction. The standard eye-piece (focal length 1.5 inches) provided a magnification of 157 and a 15' field of view.[297]

Item	Symbol	Value	Remarks
mirror diameter	D	18.7 inches	metal alloy
focal length	F	20 feet	
aperture ratio	F/D	12.8	
tube length	L	20.3 feet	
tube diameter	T	19.7 inches	octagonal
eye-piece position	-	1.3 feet	from tube mouth
mounting height	H	19.7 feet	
mounting diameter	M	18.4 feet	circle
ladder length	-	21.7 feet	at front
ladder angle	γ	65°	
finder (aperture)		2¾ inches	2° field of view

Table 2-2: Basic data of the 18.7-inch Newtonian reflector.[298]

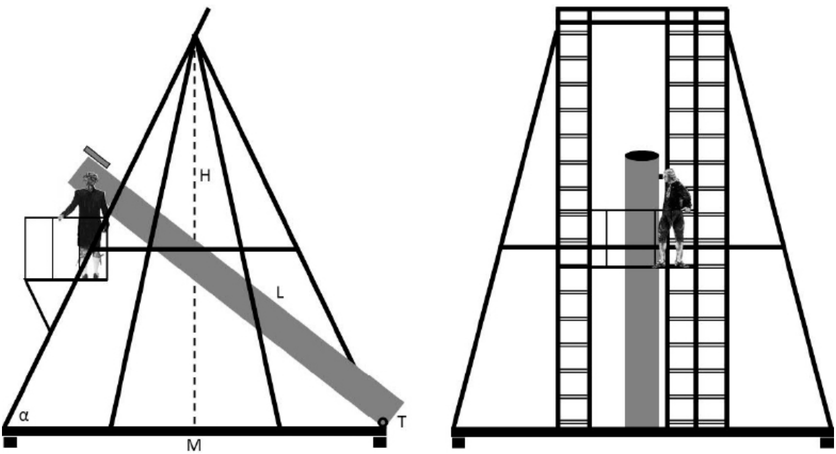


Figure 2-4: Design of the 18.7-inch telescope in 1783. At first a gallery was placed between the front ladders, to stand on; later an

observing chair was installed at the eastern ladder to reach the Newtonian focus (see Figure 2-24).

The steep, ladder-type wooden mounting allowed motions in azimuth and altitude. The entire structure was set on wheels, allowing horizontal rotations of 360°. However, Herschel mainly confined the telescope to the south meridian. The suspended octagonal wooden tube could be raised to 84° above the horizon (elevation). Thus, objects with PD $> 45°$ ($\delta < +45°$) could be observed. The eye-piece (focuser) was installed at the eastern side of the tube in a horizontal (90°) position.[299] The mounting excited Herschel's younger brother Alexander, still living in Bath, who played a significant role in all kinds of mechanical work. In November 1783, he praised the "magnificent & stupendous stand" of the new telescope.[300]

Herschel's reflector offered several motions (Table 2-3).[301] The azimuthal rotation of the stand was called 'round motion'; two workmen were needed for this task.[302] By the 'great motion' the tube was raised to a certain altitude (elevation), using a handle near the base (controlled by a workman). The 'lateral motion' allowed an azimuthal view range of about 15° (this was copied from the small 20-ft). It was operated by the observer with a handle and required some strength. This motion was applied in the first 41 sweeps, when the tube was moved sideways at a constant altitude, called 'oscillation'. In all later sweeps the tube was moved vertically, called 'sweeping motion'. It continuously swung up and down over a range of about 2° from the central position (under the control of a workman at the tube base). The 'lateral motion' was later replaced by the 'side motion' (with a fixed tube end). Controlled by a screw near the eye-piece, it allowed Herschel to track objects beyond the meridian towards the west for some minutes (fields). When the maximum azimuth shift was reached, the tube could quickly pushed back to the base position (meridian). An iron plate prevented it from moving east, which was strictly forbidden to keep the AR order (Figure 2-5).

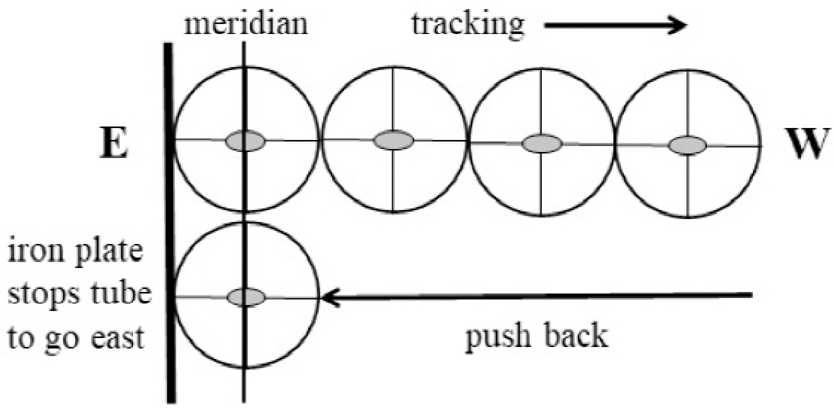


Figure 2-5: Herschel could follow an object (tracking) for a detailed study over several fields of view by the ‘side motion’ of the tube, controlled at the eye-piece (see text).

Motion	Meaning	Range	Controller	Remarks
round motion	horizontal motion of the stand	0° to 360°	workman	set to telescope direction (sweep = 180°)
great motion	vertical motion of the tube	0° to 90°	workman	set to tube elevation
sweeping motion	up/down motion of the tube	max. 4°	workman	sweep breadth
lateral motion	horizontal motion of the tube	≈15°	observer	object finding, oscillation
side motion	horizontal motion of the tube	45'	observer	tracking over several fields of view

Table 2-3: Possible motions of the 20-ft telescope (stand, tube).

2.1.2. The first 41 sweeps

On 26 October 1783, about 7:15 pm, the new 20-ft was directed to a deep-sky object for the first time. Herschel, standing on the front gallery about 2 m above the ground, observed the globular cluster M 30 in Capricornus. The impressive reflector would be used for over 30 years as the standard instrument, though being continuously modified over that time. Caroline later wrote: “not a night clear enough for observing ever passed”.303

On the 28th, after looking at Mars in Pisces at 6 pm for half an hour, Herschel again pointed the 18.7-inch to Capricornus – and tried sweeping. He applied a simple idea, allowing the inspection of a certain sky area, according to the following plan:

(1) orient the mounting in azimuth to the south meridian (azimuth 180°) by the ‘round motion’,

(2) lift the tube to a starting altitude (i.e. polar distance) by the 'great motion',

(3) use the 'lateral motion' to swing the tube by ca. 15° about the meridian ('oscillation'),

(4) when finished, change the tube elevation by 8' to 10' for another oscillation.

However, some attempts were necessary to get used to the method. About the first trial sweep, Herschel wrote in *Fixt Stars No. 5*:[304] "6^h.30'. I began to sweep, by way of trial, from ρ Capricorni to 3 degrees preceding γ (40), there are innumerable stars in this part of the heavens. The 15th & 43rd [υ & κ] Capricorni were in the parallels. My sweep is about 12 or 13 degrees. The tube being suspected in the middle. I have a double range, on both sides of the meridian." The stars ρ and γ Cap are both at declination -17° (κ Cap is 2° south of γ). This defines a starting elevation of about 20°.

Herschel then entered Aquarius. At about 7:00 pm (in the meantime some clouds had passed), he made a remarkable discovery:

In sweeping I found a nebula. Some minutes south of the parallel of the 41 Aquarii and about 2 or 3 degrees preceding the 41st. It is very obscure & must not hope to resolve it; but it appears as if composed if extremely small stars; I can however not see any of them. The evening is pretty fine tho' not the very best. Nor is my telescope in perfection so that possibly, all these obstacles being removed, I may perhaps see some of the stars a future time. A line drawn from Fomalhaut (α Piscis [Austrinus]) thro the interval between 42 & 39 Capri[corni] to the 88 Aquarii points it out. The nebula is brightest about the middle where I suspect a star, and of an extended form. When I have the 41st in the lower part of the field I sweep upon it.

The nebula is the 10.9 mag galaxy NGC 7184; a sketch was made but no coordinates were determined (Figure 2-6). It was Herschel's first discovery of a galaxy. The object was later catalogued as II 1, the first entry of the 2nd class, 'faint nebulae'. This observation terminated the trial sweep.

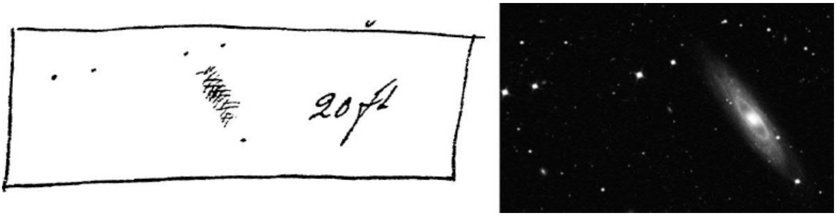


Figure 2-6: Herschel's first discovery with the 20-ft (28 October 1784): the elongated 10.9 mag galaxy NGC 7184 in Aquarius; note the striking star chain.

On the next day, 29 October, Herschel explained his method in more detail:

My sweeping last night not being sufficiently marked out I shall not reckon it, but begin this evening to number the sweeps. My method is to direct the telescope to the meridian & it being suspected there I sweep with it on both sides to an extent pf [preceding-following] about 6 or 6½ degrees on each but for precautions take I shall only rate them at 5 degrees on each side. I mark down the star in the meridian & a star in the parallel I go on this being done every rows & then will give the space swept over sufficiently true. I suppose my field of view to be about 12 minutes & power nearly 120, single eye lens; and every time I alter the altitude I make a change of about 6 or at most 8 minutes that I may not miss any stars between the sweeps.

In 1786, Herschel gave 'a short history of this 20-feet telescope', explaining his early sweep method of horizontal oscillations:[305]

In the month of October of the already mentioned year [1783] I began to use it, being then mounted on its present stand, but with a lateral motion under the point of support of the great speculum, by which its direction could be changed about 15 degrees. It had also a kind of moveable gallery in front, about nine feet long, which permitted me to follow a celestial object near 15 degrees more; by which means I obtained a range of 30 degrees without moving the stand. The Newtonian form has the capital advantage of rendering observations equally commodious in all altitudes; I had therefore placed the instrument in the meridian, that I might view the stars in their most favourable situation.

When I had seen most of the objects I wished to examine, I proceeded to the work of a general review of the heavens. The first method that occurred was, to suffer the telescope to hang freely in the center; then, walking backwards and forwards on the moveable gallery, I drew the instrument from that position by a handle fastened to a place near the eye-glass, so as to make it follow me, and perform a kind of very slow oscillations of 12 or 14 degrees in breadth, each taking up generally from 4 to 5 minutes of time. At the end of each oscillation 1 made a short memorandum of the objects I chanced to see; and when a new nebula or cluster of stars came in my way, I made a delineation of the stars in the field of view, both of the finder and of the telescope, that it might serve me to find them again. This being done, the instrument was, by means of a fine motion under my hands, either lowered or raised about 8 or 10 minutes, and another oscillation was then performed like the first. Thus I continued generally for about 10, 20, or 30 oscillations, according as circumstances would permit; and the whole of it was then called a Sweep, and as such numbered and registered in my journal.

Since the tube length was 6 m, the maximum oscillation range was about 1.5 m. The ‘moveable gallery in front’ was a shaky item and the sweep process fatiguing and dangerous, so Caroline feared for William’s safety:306

My Brother began his series of Sweeps when the Instrument was yet in a very unfinished state, and my feelings were not very comfortable when every moment I was alarmed by a crash or fall; knowing him to be elevated 15 or 16 feet on a temporary cross beam instead of a save gallery. The ladders had not even their braces at the bottom and on one night in a very high wind he hardly had touched the ground before the whole apparatus came down; some neighbouring men were called up to help extricating the mirror which was fortunately uninjured; but much work for the Carpenters was cut out for next day.

The official ‘sweep no. 1’ was performed on 29 October after Herschel had viewed the third satellite of Saturn (Thetis) in Sagittarius. He turned the reflector eastwards to Capricornus and performed 12 oscillations. “158 combinations of stars” were

counted (a term used for star patterns). This night also saw sweeps no. 2, 3 and 4. The second one started about 8:40 pm at -15° declination; 23 oscillations were made in Aquarius and Cetus. Here "several fields without stars" and "vacant spaces" were detected. Such empty regions would later play a major role in Herschel's investigation of the Milky Way's structure. Sweep no. 3 (24 oscillations) continued in Cetus and no. 4 (27 oscillations) ended in Eridanus. No new non-stellar objects were seen in that night. However, in the 4th sweep, Herschel encountered M 77 near δ Cet, known from the observation on 20 September with the small 20-ft.

William's description	**Identification**
The 12th Monocerotis appears like a nebulous star. In the sweeper (small instrument) it consists of 6 stars arranged in pairs with many small ones.	Flamsteed's open cluster NGC 2244 (4.8 mag), independently found by Herschel on 22 October 1781
[Following] 56th Andromeda, like a nebulous star. It is a small cluster.	NGC 752 in Andromeda (discovered by Caroline a month before)
In Cancer, appears like a nebula.	Praesepe (M 44)
9 & 10 Monocerotis, like a nebulous star, consists of 4 or 5 large stars.	open cluster NGC 2232 in Monoceros, Herschel's first deep-sky discovery on 5 December 1779
South preceding ξ Geminorum, like a nebulous star; consists of a bright triangle and small stars.	probably a group of 5-6 mag stars,[307] 3.5° southwest of ξ Gem
More south preceding ξ Geminorum towards μ Orionis another nebulous star; it consists of a great number of stars.	probably a group of 6–7 mag stars, 5° southwest of ξ Gem
ξ Arietis appears like a small nebula & consist of 6 or 7 large stars.	a group of 5-6 mag stars, spread over 45'
φ Aurigae appears like a small nebula. There are a great many stars.	there is a star cluster (Stock 8) around φ Aur, but the members are beyond 6th mag and the diameter is only 15'

Table 2-4: Objects seen by Herschel with the naked eye on 29 October 1783.

The very clear night of 29 October also brought a testimony of Herschel's exceptional eyesight, both concerning light-gathering power and resolution. Under the heading 'Nebulas visible to the naked eye', eight objects are listed (Table 2-4).[308] He also viewed "double stars to the naked eye": ε Lyr ("very difficult to be seen double"), θ Tau ("pretty"), α Cap and ι Ori.[309]

In the following night of 30 October, sweeps 5–9 were made in Capricornus, Aquarius, Cetus, Piscis Austrinus and Sculptor with a "much improved [18.7-inch mirror] by going on with polishing". This fact illustrates that Herschel literally worked day and night! In sweep 6, he wrote: "δ Aquarii M&P [meridian & parallel], contains much very faint nebulosity with exceedingly small stars, it is in patches which I suspect all to be stars". However, there is nothing like that near the star. In sweep 7, a new nebula was discovered 3.3° northeast of Fomalhaut (α PsA). Located at a declination of -28.5°, it was only 10° above the horizon. Herschel noted: "In the telescope this nebula is situated between three very small stars forming an arch or triangle with them, as in the figure. The diameter of this nebula may be near 20" and it may perhaps be a comet." This was not a comet,[310] but the 10.4 mag galaxy NGC 7507 (II 2) in Sculptor, Herschel's second galaxy after NGC 7184 of the trial sweep. His sketch is correct. Sweep 8 yielded another find in Sculptor, located 20° further east at the border to Cetus. The object was only 13° above the horizon. However, the "beautiful nebula" turned out to be Caroline's NGC 253, discovered on 23 September (see section 1.9).[311] This bright southern galaxy is her most important deep-sky object. It was later catalogued as V 1, the first entry of Herschel's class V, 'large nebulae'. NGC 253 was again observed on 27 October 1785 (sweep 467) and 19 September 1786 (sweep 593).

In sweep 15 (3 November), Herschel gave the duration of the oscillations. The values were taken from a modified clock, showing GMT + 12^h (avoiding a change at midnight). Each of the 14 oscillations lasted about 4–5 minutes. After sweeping, the Orion Nebula (M 42) reached the meridian and was observed with the

18.7-inch for the first time: “on the north of the nebula about this star [NU Ori] is another smaller nebula joining to it which is much fainter”. Although being familiar with the *Messier Catalogue*, the appendix of M 42 was not identified as M 43 (found by Mairan in 1731). Then another part, located 4' east of the Trapezium, was seen as a separate object: “in the open black part of the nebula is a small distinct nebula of an extended shape”. It was later catalogued as III 1, the first object in Herschel’s 3rd class, ‘very faint nebulae’; it bears no NGC-number. He was convinced that “other instruments did never shew [it]”.[312] In the same night (after sweep 17), Uranus was seen in the large reflector for the first time.[313] It is interesting that, to view it in Gemini, the tube must reach an elevation of 60°. This was pretty high for the observer platform (17 feet above the ground), mounted at the still incomplete telescope. Obviously, Herschel was eager to view the planet – despite all risks! He was mainly interested to find satellites and had formerly used the small 20-ft in various occasions. Such observations were continued in the sweeps of 1784 and 1785.[314]

The night of 19 November saw five sweeps (23–27), mainly in southern constellations. In sweep 25, Herschel analysed Sirius with a prism, held in front of the eye-piece: “I can count the lines of a page of the transactions by its light. I refracted it thro’ a prism & saw all the prismatic colours in the telescope very distinctly.”[315] In sweep 26 he saw M 41, the bright open cluster below Sirius (see Figure 1-33). Then he turned north to view Uranus again. About 8° east, he saw a “Cluster of stars, very beautiful and of a considerable extent, perhaps 6 or 8'. It is 2 degrees south following p (60) Geminorum; in a line continued from (48) m through p. I counted 50 or more and suspect double that number. The stars are close.” Although Herschel’s description of the place is incorrect, there is no doubt that he discovered the open cluster NGC 2420 in Gemini, shining at 8.3 mag.[316] It was later catalogued as VI 1, the first object of the 6th class, ‘very compressed and rich star clusters’. The object was seen the record number of nine times in the sweep campaign.

In that night the tube elevation was raised from the former maximum of 33° to 61°. The eye-piece position is impossible for the observer to reach on the front gallery in the configuration shown in

Figure 2-4. But Herschel had already solved the problem: a bar was installed at the bottom, leading from the peripheral ring of the stand to its centre. The tube end could be moved forward by rollers on this bar; this is called the ‘bar motion’.[317] The clever tool enabled the observer to work at higher elevations (Figure 2-7).

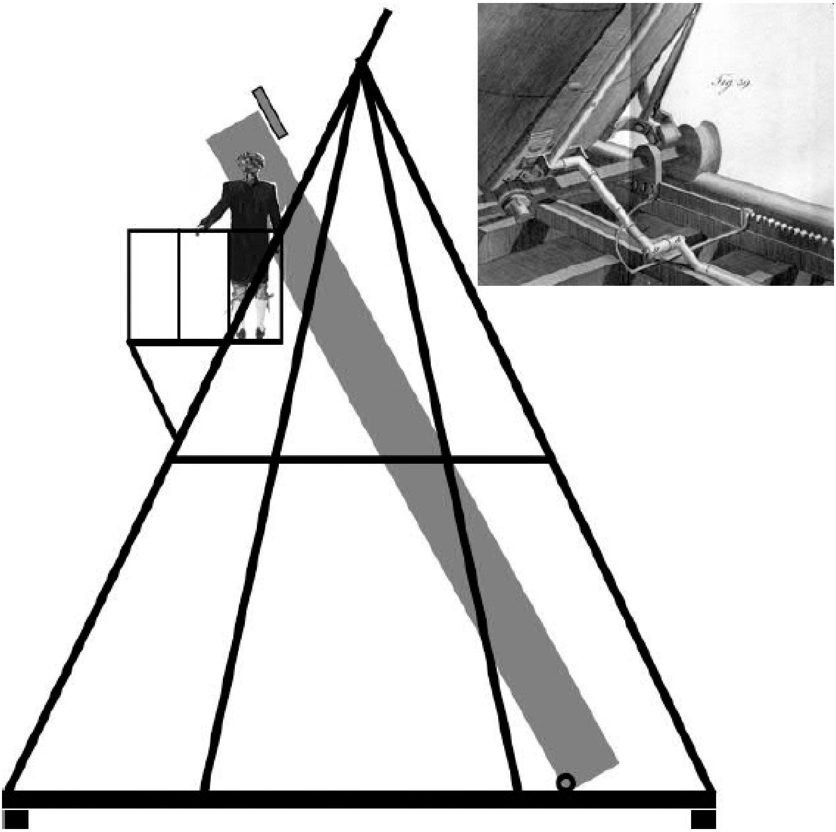


Figure 2-7: Herschel’s ‘bar motion’, a mechanism to shift the tube end towards the centre. Now the observer on the front gallery had access to the eye-piece at higher elevations. The inset shows the mechanism, made for the 40-ft telescope.[318]

In sweep 29 (20 November), clouds interrupted the observing session after three oscillations. Herschel used the break to test a new viewing method: “I tried to look in at the front of the telescope by finding the eye glass to the inner side of the tube at the requisite distance, and found the telescope act incomparably better tho’

under the greatest disadvantage of a proper situation for myself." At the end of *Journal No. 7,* he noted: "Tried the front view and found it incomparably better and brighter than the Newtonian." This was the first test of the famous 'front-view' method with the 20-ft, though not the first ever. Several years earlier (on 28 March 1776), Herschel wrote: "I tried a 10 feet mirror without the small one, looking in at the front of the tube, and holding the eye glass in my hand. I liked the method very well."[319] At the 20-ft, Herschel used the standard eye-piece of 15' field of view and 157 ×. However, in this hand-held use, the eye-piece focus is pretty unstable. The alternate optical design was invented already in 1732 by Lemaire (Figure 2-8).[320] It is very unlikely that Herschel was aware of this.

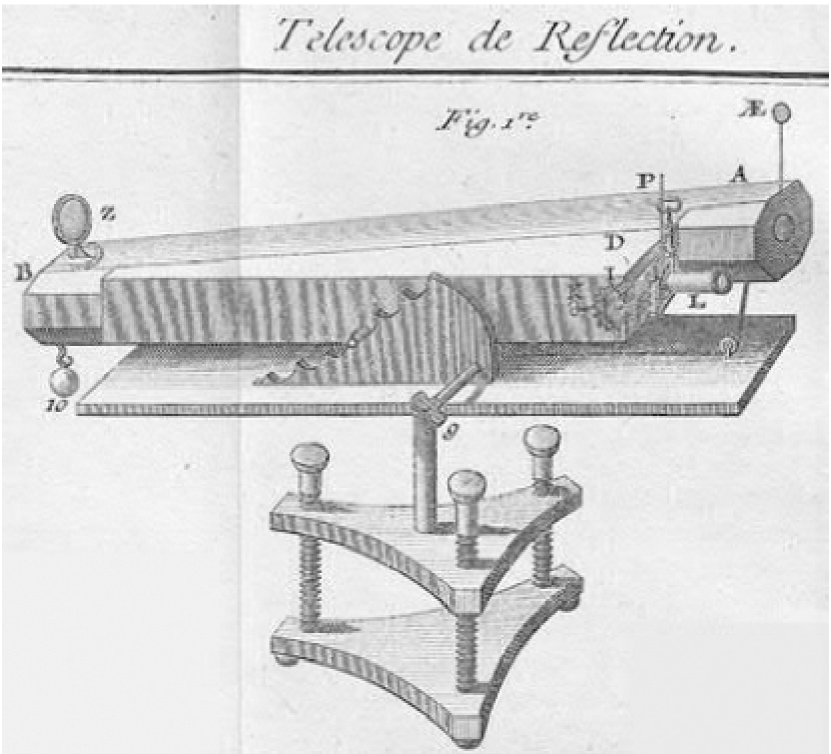


Figure 2-8: The front-view reflector, invented by Jacques Lemaire in 1732.

On 29 November, no sweep was made. Herschel observed double stars with the 7-ft. He had two guests: "I shewed Mr. Nairne &

Collins Mr. Pigotts Comet."[321] The object, found by Edward Pigott on the 19th (known as the Great Comet of 1783), was in Aries with a magnitude of 7.2.

In sweep 35 of 3 December, Herschel discovered the 9.3 mag open cluster NGC 2509: "Cluster of stars ¾° under a star (visible to the naked eye) preceding 16 Navis [16 Pup]". It was later catalogued as VIII 1, the first object of the 8th class, 'coarsely scattered clusters of stars'.

From the trial (28 October) to sweep 41 (13 December), Herschel found four deep-sky objects in 12 nights: two open clusters (NGC 2402, NGC 2509) and two galaxies (NGC 7184, NGC 7507). He was dissatisfied, expecting more from his new method. However, there are two more finds, not catalogued at that time.[322] In sweep 35, after the discovery of NGC 2509 in oscillation 8, Herschel noted: "Another cluster of stars preceding, in the same parallel under the 2nd Navis [2 Pup]." This is NGC 2432 (Figure 2-9). Later, in oscillation 13, we read: "A cluster under the 2nd cluster of the 8th oscillation, and many secondary clusters more." Due to the declination difference between the oscillations, this might be NGC 2421.

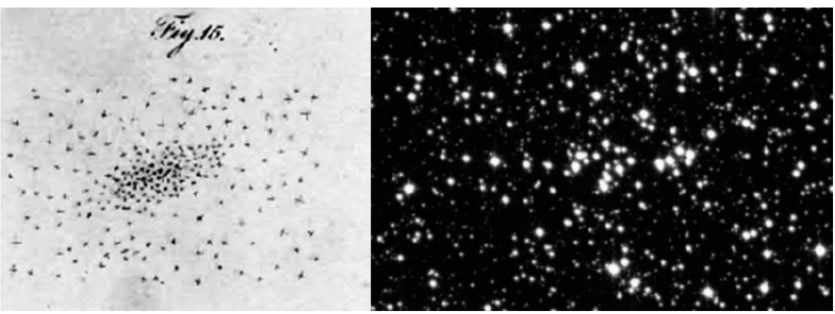


Figure 2-9: The 10.2 mag open cluster NGC 2432 in Puppis was found on 3 December 1783 (sweep 35), but not catalogued; the sketch was made on 4 March 1790 (sweep 934).

Between 20 November and 3 December, no sweep was made. In the early period, sweeping was often interrupted by other observations. Herschel viewed the planets Mercury, Venus, Mars and Uranus with the 7- and 10-ft reflectors.[323] But, no doubt the new 20-ft gradually

became the dominating instrument.

2.1.3. A new sweeping method and Caroline's participation

Discovering only six deep-sky objects over a period of six weeks, was not the desired yield. Herschel was convinced that the reason was not a lack of skills as an observer. The method had its weak points. First there was the fatiguing work: oscillating the tube, interrupted by noting time and descriptions on paper, held by a tray. Secondly, the necessary candlelight caused a frequent loss of dark adaptation, which implied that some objects were overlooked. An intelligent solution was needed.

13 December 1783 was the day of change. Sweep 41 was still made in the usual manner. The first oscillation (of 24) started at about 5:45 pm with 97 Aqr in the meridian (declination -15°). The sweep ended at 6:30 pm, "1° after g [2 Cet]"; this star is 2° south of 97 Aqr.

With sweep 42, only 10 minutes later, Herschel abruptly altered his method from sweeping horizontally to vertically! The telescope now basically acts like a transit instrument.[324] By the new method a certain rectangular sky area was covered. The vertical 'sweeping motion', using ropes and pulleys at the back of the telescope, was controlled by a workman located near the tube base. A sweep was now made in a different manner:

(1) fix the mounting in azimuth to the south meridian,

(2) lift the tube to a starting altitude (mean PD) by the 'great motion',

(3) regularly move the tube up and down from the mean PD by about 2° ('sweeping motion'),

(4) let the objects pass through the field of view from east to west due to the Earth's rotation.

The starting target in sweep 42 was 8 (ι) Cet, about 8° north of the final position of sweep 41. Herschel noted: "From the 8th Ceti to 5

degrees following; a zone of about 1½ degrees; upwards.” Thus, the sweep area was 20^{m} in right ascension and 1.5° in declination. He added a memorandum, describing his new method:[325]

I now began to sweep in a different manner, which I find much more convenient & also better in as much as it gives me an opportunity to determine the place that has been examined. The method is as follows: I place the telescope in or near the meridian; then raise and depress it alternately, so far as to return in a different tract of stars. By experience I find that my perpendicular sweep may be about 1½ degree about the equator. So that now I have zones of sweeps that remain between the same parallels. By noting the time of the passage of known stars I can determine the AR of unknown objects to a few minutes; & on comparing their altitude with these stars, can also have the declination to a few minutes. An instrument might easily be constructed, in this manner to act as a good transit; at least with sufficient accuracy to determine the place of any object so far as to point out with pretty considerable precision.

The text mentions an important point. The horizontal oscillations gave no coordinates; the object position was given by a sketch and/or textual description. This would change now. In the preface of his first published catalogue of nebulae and star clusters (1786), Herschel again summarized the unsatisfactory situation of the first 41 horizontal sweeps and his solution:[326]

When I had completed 41 Sweeps, the disadvantages of this method were too evident to proceed any longer. By going into the light so often as was necessary to write down my observations, the eye could never return to that full dilatation of the iris which is absolutely required for delicate observations. The difficulty also of keeping a proper memorandum of the parts of the heavens which had been examined in so irregular a manner, intermixed with many short and long stops while I was writing, as well as the fatigue attending the motion, upon a not very convenient gallery, with a telescope in my hands of no little weight, especially at the extremes of the oscillations, where it made a considerable arch upwards, were sufficient motives to induce me to look out for another method of sweeping. And it is evident, that the places of nebulae

hitherto determined, which was till the 13th of December, 1783, must be liable to great inaccuracy. I therefore began now to sweep with a vertical motion; and as this increased the labour of continually elevating and depressing the telescope by hand, I called in the assistance of a workman to do that part of the business, by which means I could observe very commodiously, and for a much longer time than before.

What does “at the extremes of the oscillations, where it made a considerable arch upwards” mean? The tube was held by ropes, fixed at the top of the stand. Thus, a horizontal shift let it move on a circular path, like a pendulum. Depending on the shift angle, the tube goes up by several inches. The observer must stretch himself to reach the eye-piece. This problem was now eliminated.

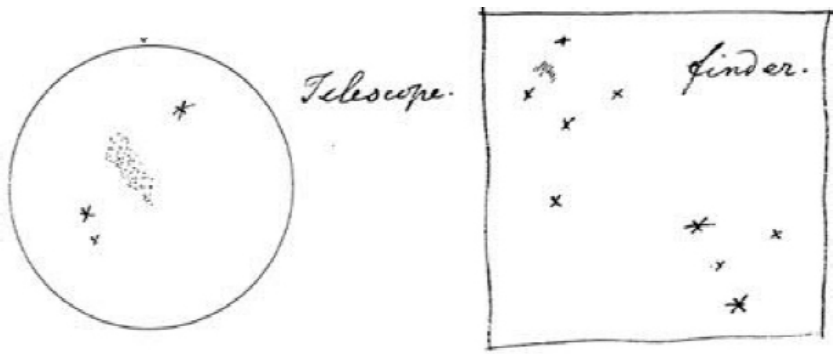


Figure 2-10: The first object discovered with the new vertical sweep method: the 10.4 mag galaxy NGC 157 (II 3) in Cetus, seen on 13 December 1783 in sweep 42. To fix the position, Herschel made sketches of the telescopic and finder views.

Already sweep 42 brought a new nebula, entering the field of view after 15 minutes: “About 5 deg following & 1 degree above the parallel of the 8th (ι) Ceti, between the two considerable stars visible in the finder; but the nebula cannot be seen in it.”[327] Herschel made sketches of the finder and telescope views. The object is the 10.4 mag galaxy NGC 157 (II 3), 3.8° east of ι Cet (Figure 2-10).

Three more vertical sweeps were made in the night of 13 December, but nothing else was found. Sweep 43 covered an area of 30^m in AR

and 2.5° in declination, reaching from φ^1 (17) Cet to 37 Cet (mean δ = -12°). Was the new method actually more successful? Certainly. It was not only more convenient, but also had the potential for important technical and observational improvements.

In sweep 44, Herschel saw a "comet or nebulous star not visible in the finder". Based on the starting point and time of the sweep (θ Cet at 8:15 pm), Herschel determined a rough position for the strange object: "It entered the telescope at 8^h 24', therefore its distance in time is 9' from θ Ceti. The star κ [Cet] is nearly in the parallel of the nebula […] 2° north following θ Ceti." Thus, the object is located 9^m east and 2° south of θ Cet. There is no doubt that he saw the 10.9 mag galaxy NGC 596 (II 4) in Cetus; the place is fairly good. On 17 December (when no sweep was made), Herschel checked the situation: "I saw the cloudy star which I suspected to be a comet but it is nearly in the same situation where I saw it last Saturday [13 December]. It is possible it may have moved a minute or two but not more." The next night (18 December), he still was in doubt: "I shewed Dr Lind the new nebula or comet. There is no evident change of place tho' I rather suspect it have been retrograde; but without measures there is no dependence on small motions."

Sweep 45 lasted only 10 minutes in an area about ζ Cet; Herschel noted: "The Moon is pretty bright & it is not safe to go on." Altogether, he found two nebulae in the first night he used the new sweeping method. No doubt he was on the right track.

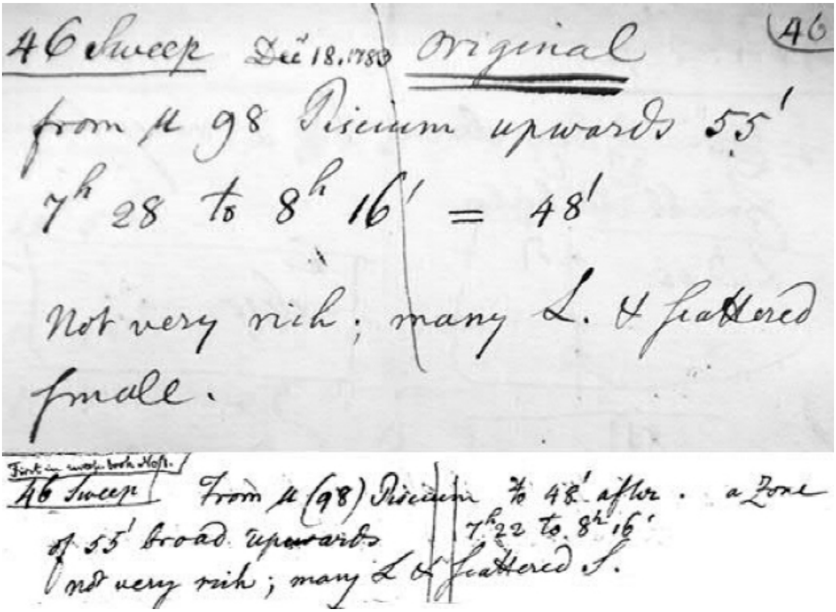
In the period from 13 to 18 December, Herschel had another idea. It was difficult for him to record the observational results at the telescope. The task was time consuming, and when using candlelight his dark adaptation was frequently lost.[328] So William decided that an external person was needed to write down the main data in real time – and he already knew the best choice for this task: Caroline. She was promptly positioned at a desk in a ground-floor room next to the telescope.[329] William shouted an account of his observation to her, waiting at the open window. While writing the information down, she repeated it, which sometimes led to corrections. Now Herschel enjoyed much more freedom at the eye-piece.[330] In 1786, he wrote:[331]

Soon after [changing the sweep method] I removed also the only then remaining obstacle to seeing well, by recourse to an assistant, whose care it was to write down, and at the same time loudly to repeat after me, every thing I required to be written down. In this manner all the descriptions of nebulae and other observations were recorded; by which I obtained the singular advantage that the descriptions were actually writing and repeating to me while I had the object before my eye, and could at pleasure correct them, whenever they disagreed with the picture before me without looking from it.

2.1.4. Book-keeping: sweep records

In sweeps 1–45, William was alone in the night, with the exception of the workman on the ground. Notes were directly made at the telescope. They were copied into *Journal No. 7*, in a break between two sweeps, immediately after finishing the last sweep, or at the latest on the next day. Unfortunately, Herschel destroyed all notes made at the telescope, probably thinking they were too rough and not worth keeping.

Starting with sweep 46 on 18 December, Caroline assisted her brother. Several items were present on her desk: a candle, paper and pen, a clock and the *Atlas Coelestis*. She wrote down the brief information, coming from William at the telescope, and the corresponding time. Alas, her first-hand are also lost. However, they were timely copied in a new document, titled *Sweeps No. 1* (Figure 2-11). Being Caroline's first sweep record series, it was called 'Original'; the second is the revised version, discussed below (see Table 2-5).


46 Sweep Dec. 18, 1783 Original (46)
from μ 98 Piscium upwards 55'
7h 28 to 8h 16' = 48'
Not very rich; many L. & scattered small.

First in sweep book No. 1
46 Sweep From μ (98) Piscium 48' after . a Zone of 55' broad upwards 7h 22 to 8h 16'
not very rich; many L & scattered S.

Figure 2-11: Top: Caroline's first entry in her new document *Sweeps No. 1* ('Original'). Bottom: The corresponding record in William's *Journal No. 7* (note his remark "First in sweep book No. 1").

In the introduction of *Sweeps No. 1*, Caroline wrote down her brother's words:

Before these sweeps in the meridian were made, I made 45 in the parallel. See Journal. Those 45 were made by swinging the suspected telescope backwards and forwards. See page 450 Fixt Stars [sentence later added]. The stroke with a pen drawn through the sweeps in this book only denote that the observations were transcribed into the journal generally the very morning after they were made. The first 15 sweeps were made by mean time [GMT], the 62 sweep sidereal time was used.[332]

The existence of Caroline's sweep document does not mean that William stopped his own recordings, made at the telescope with paper, pen and candlelight. The reason is simple: complex information, like sketches, could not be shouted to Caroline! The records were still copied by him into the *Journal*. In a final step all information was joined by William into the *Fixt Stars* series,

originally created for the star reviews. Here all looks pretty clean and neat. A vertical stroke in the *Journal* and in Caroline's *Sweeps* marks the copied text.333 Figure 2-12 show the various versions in case of the sweeps 61, 62 and 63. There are similarities and differences.

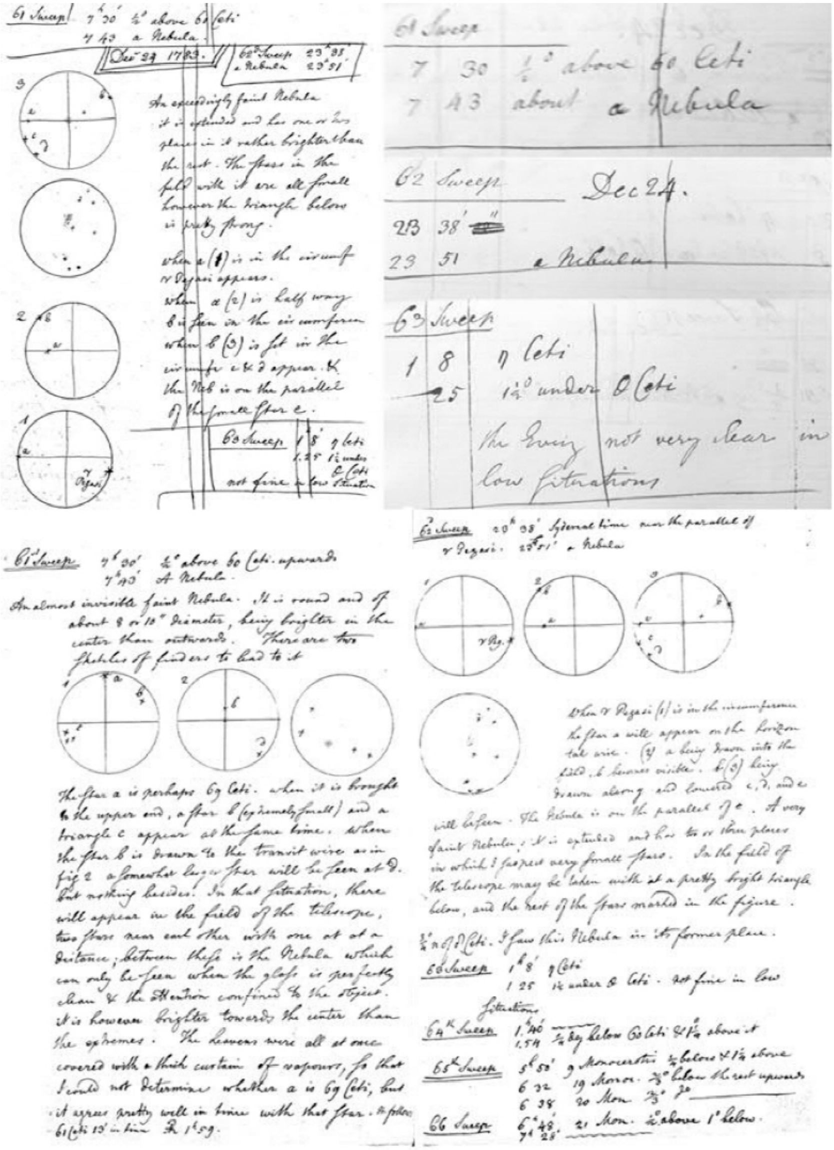


Figure 2-12: William's *Journal No. 7* (top left), Caroline's *Sweeps No.*

1 (top right) and the copy in *Fixt Stars No. 5* (see text).

To analyse Figure 2-12, let us denote: (1) = William's *Journal No. 7*, (2) = Caroline's *Sweeps No. 1*, (3) = William's *Fixt Stars No. 5*. We find that for sweep 61, (1) and (2) give the same brief data (GMT, 'nebula'). Because only Caroline read the clock (2), William must have copied her data into (1). Astonishingly, in (3) we find a longer account about the discovered 'nebula', missing in the former documents! This is the 12.9 mag galaxy NGC 867 (III 2) in Cetus. The data came from William's recording at the telescope. Obviously, there was a reason to copy them directly into his final document (3), instead of (1). Caroline's record for sweep 62 is very short (2); she did not even mention that sidereal time now used. William's telescope notes are in (1), though not complete. We see in (3) that another nebula was observed "in its former place". This is NGC 1032 (II 5), found in sweep 47 (18 December). Sweep 63 agrees in all three documents.

Herschel's second document, the *Fixt Stars*, was closed on 12 July 1784 with sweep 236. The last entry in No. 7 ends abruptly in the middle of a sentence ("I passed on…"). However, the full record is given in *Journal No. 9*. The vertical 'stroke with a pen', indicating a copy also ends abruptly in the mentioned sentence.[334]

William's records concerning sweeps terminate with *Journal No. 9*. The last entry was made for sweep 259 on 7 September 1784. *Journal No. 10A*, starting on 8 September 1784 (sweep 260) was written by Caroline; it ends on 21 December 1784 (sweep 350). Obviously, the siblings found it useless to write down the primary information at several places.[335] From 1785 to 1799, Caroline's *Sweeps* series was the only document. It appeared in seven parts, containing all sweeps from number 46 (18 December 1783) to 1112 (30 September 1802).[336]

Document	Author	Sweeps	Dates	Archive	Remarks
Journal No. 7	W	1–150	29 Oct. 1783 – 19 Feb. 1784	RAS W.2/1.7	
Journal No. 8	W	150–210	19 Feb. 1784 – 9 May 1784	RAS W.2/1.8	
Journal No. 9	W	211–259	11 May 1784 – 7 Sep. 1784	RAS W.2/1.9	
Journal No. 10A	C	260–350	8 Sep. 1784 – 21 Dec. 1784	RAS W.2/1.10A	
Fixt Stars Vol. 5	W	1–79	29 Oct. 1783 – 17 Jan. 1784	RAS W.4/1.5	
Fixt Stars Vol. 6	W	80–191	18 Jan. 1784 – 13 Apr. 1784	RAS W.4/1.6	
Fixt Stars Vol. 7	W	191–236	13 Apr. 1784 – 12 Jul. 1784	RAS W.4/1.7	
Sweeps No. 1	C	46–141	18 Dec. 1783 – 13 Feb. 1784	RS MS/272	'Original'
Sweeps No. 2	C	142–191	13 Feb. 1784 – 13 Apr. 1784	RS MS/273	'Original'
Sweeps No. 3	C	191–353	13 Apr. 1784 – 6 Jan. 1785	RS MS/274	'Original'
Sweeps No. 4	C	351–452	6 Jan. 1785 – 3 Oct. 1785	RS MS/275	'Original'
Sweeps No. 5	C	453–609	3 Oct. 1785 – 13 Oct. 1786	RS MS/276	'Original'
Sweeps No. 6	C	610–917	14 Oct. 1786 – 23 Mar. 1789	RS MS/277	'Original'
Sweeps No. 7	C	918–1113	26 Mar. 1789 – 31 May 1813	RS MS/278	'Original'
Sweep Records No. 1	C	46–206	18 Dec. 1783 – 24 Apr. 1784	RAS W.2/3.1	Revision
Sweep Records No. 2	C	207–279	25 Apr. 1784 – 20 Sep. 1784	RAS W.2/3.2	Revision
Sweep Records No. 3	C	280–387	20 Sep. 1784 – 13 Mar. 1785	RAS W.2/3.3	Revision
Sweep Records No. 4	C	388–485	13 Mar. 1785 – 7 Dec. 1785	RAS W.2/3.4	Revision
Sweep Records No. 5	C	486–598	7 Dec. 1785 – 21 Sep. 1786	RAS W.2/3.5	Revision
Sweep Records No. 6	C	599–765	21 Sep. 1786 – 14 Oct, 1787	RAS W.2/3.6	Revision
Sweep Records No. 7	C	766–953	14 Oct, 1787 – 19 Mar. 1790	RAS W.2/3.7	Revision
Sweep Records No. 8	C	954–1112	20 Mar. 1790 – 30 Sep. 1802	RAS W.2/3.8	Revision

Table 2-5: Documents with sweep data (W = William, C = Caroline); *Royal Society* (RS), *Royal Astronomical Society* (RAS). The order of the four series reflects the different versions, made over the years (for earlier documents, see Table 1-3).

In June 1799, Caroline started to work on another series, called *Sweep Records*. In eight parts it contains sweeps 46–1112. The reason for the new document was a complete revision of all sweep observations. The data were checked for identifications, enhanced by additional notes and put in a homogenous form. All positions were calculated for the year 1800. Objects were given a 'General number', running from 1 to 2508, according to the discovery date and time.[337] In total, we have four sources of sweep data (Table 2-5): *Journal*, *Fixt Stars*, *Sweeps* and *Sweep Records* (the *Review* series plays no role here).[338] Figure 2-13 shows sweep 174 in the four documents.

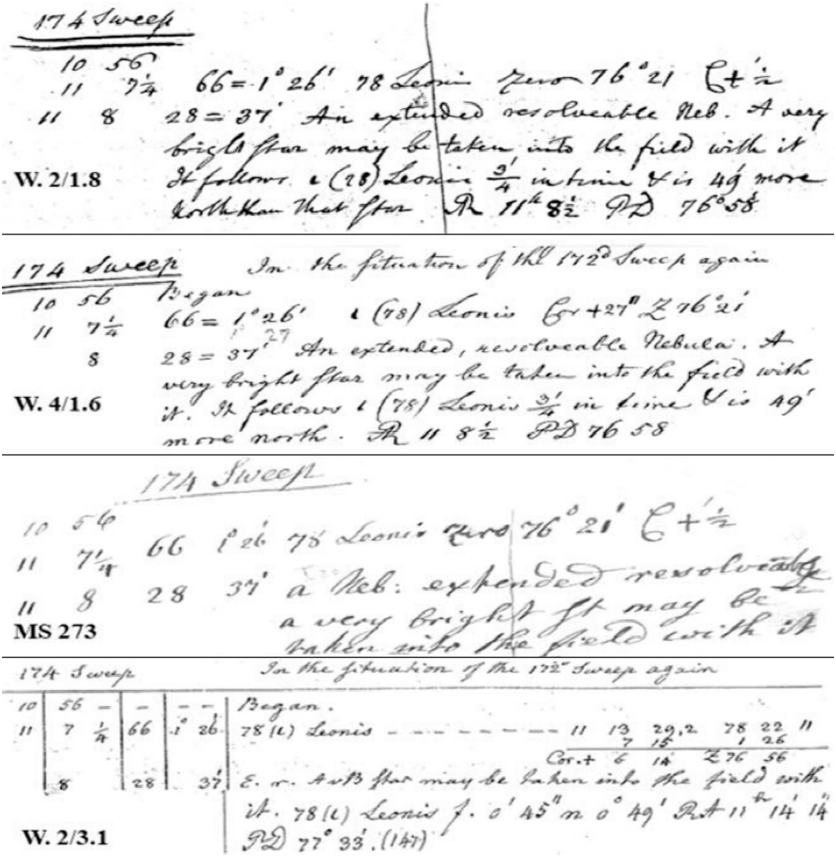
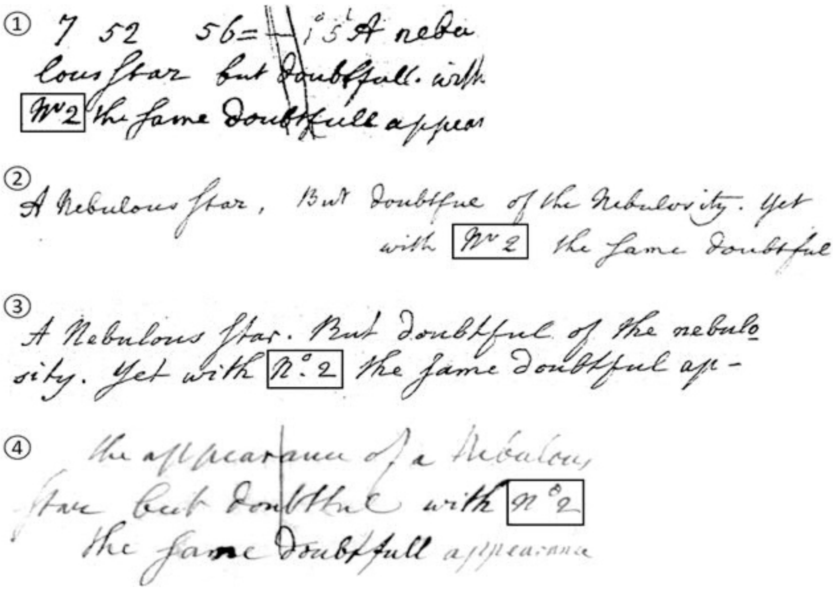


Figure 2-13: Sweep 174 made on 15 March 1784 at Datchet appears in the four documents: *Journal No. 8*, *Fixt Stars No. 6*, *Sweeps No. 2* and *Sweep Records No. 1* (from above). Bold = RAS/RS archive documents.

Who is the author of a certain text? Dreyer wrote that the "handwritings of brother and sister were wonderfully alike". This is generally true. However, there are some striking differences, for instance, the notation of 'Nr.' (Figure 2-14). The texts 1 and 2 are written by William (*Journal*, *Fixt Stars*), whereas 3 and 4 are due to Caroline (*Sweeps*, *Sweep records*).


① 7 52 56 = 1° 5' A nebulous star but doubtfull. with No 2 the same doubtfull appear

② A Nebulous star, But doubtful of the Nebulosity. Yet with No 2 the same doubtful

③ A Nebulous star. But doubtful of the nebulosity. Yet with No. 2 the same doubtful ap-

④ the appearance of a Nebulous star but doubtful with No 2 the same doubtfull appearance

Figure 2-14: Different handwritings uncover the author (see text).

The sweep records contain several categories of observed objects (Table 2-6). Moreover, situations or conditions are mentioned, like air/sky (clear, hazy, twilight), weather (clouds, wind, temperature), moonlight or transient phenomena (aurora, meteor).

Category	Remarks
new non-stellar object	'General number' (1–2500, in brackets)
Messier object	'Connoissance des Temps'
suspected object, patch	not catalogued
deception	often proved with higher power
affected region	region with diffused milky nebulosity' (AR, PD limits)
reference star	Flamsteed, Wollaston, Bode (see Table 5-2)
star	known (not used as reference)
unknown star	U + superscript number (not in *British Catalogue*)
omitted star	O + superscript number (star measured by Flamsteed but not inserted in *British Catalogue*)

coloured (red) star	mostly unknown (U)
double/multiple star	known (catalogue designation), new (N)
gage	from single or multiple fields (mean value)
vacant place	AR, PD limits
planet	Jupiter, Saturn, Uranus

Table 2-6: Object categories in Caroline's sweep records. AR and PD refer to the right ascension and North Polar Distance of the region, following the notation in the *British Catalogue*, which was used as a reference by Herschel.[339]

In 1799, Caroline explained the situation, concerning the various documents. However, she incorrectly mentions that *Journal No. 10A* contains the sweeps up to 353 (instead of 350).[340] We read:[341]

At the time when these observations [sweeps] were began, the method of keeping the Journals, was not brought under those plain and correct rules by which they are now kept, it was therefore necessary to consult as far as to the 236th sweep not only the Original [*Sweeps* series], but also the Journals No. 7, 8, 9, 10A; and the Fixt Stars Vol. 5, 6, and 7. From 236 sweep to 353 the Journals No. 9, 10A, and the Original were referred to in making this transcript; but from 354 sweep on to the present number we have only the Original.

NB. The Original has been strictly adhered to (in preference to the other books) with regard to the time, and the particulars which pointed out the polar distance of objects; but as in the Original the descriptions were not completed, they purposely omitted namely the copying of the figures of the view of the finder and telescope, which as far as the 154th sweep were given almost with every nebula or cluster, by way of describing their situation and appearance. My reason of not copying them was a fear of not being able to do them well enough, or at least not as correct as they may be seen in the Volumes of the Fixt Stars and Journals.

Caroline also kept a record for every single non-stellar object found in the sweeps. Because 2508 were numbered, we have the same number of 'Register sheets'. There, all relevant information was

copied on foolscap. The same work was done for every single Messier object and double/multiple star, respectively.342

Caroline's *Sweep Records*, 'Register sheets' and other compilations, like the legendary *Zone Catalogue*, were handed over in 1863 to the *Royal Society* by John Herschel. All other documents were given in 1917 to the *Royal Astronomical Society* (RAS) by the late William James Herschel.343 In 1918, Dreyer compiled the content of the RAS Herschel Archive.344

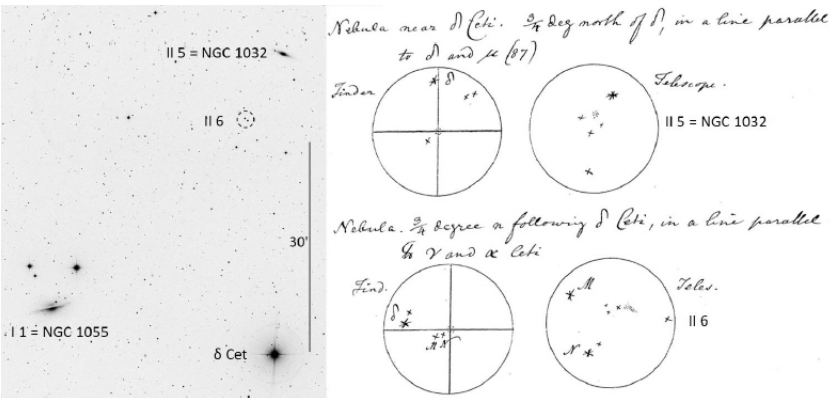


Figure 2-15: The strange case of the nebulae near δ Cet (see text)

The content of the series differs; sweep 47 (18 December 1783) is an example. In that night, Herschel discovered two objects (Figure 2-15). *Sweeps No. 1* gives: "3/4 deg above δ [Ceti] a very faint nebula" and shortly after another "very small nebula" was seen "1/2° above δ", adding "both these are like comets". Sketches of the finder views show their places, a telescopic view their shape.345 In the reflector the former nebula forms a square with three stars, marked in another sketch. The objects were later catalogued as II 5 and II 6 (a pair of stars). *Journal No. 7* and *Fixt Stars Vol. 5* do not mention the discovery. Finally, in *Sweep Records No. 1* we find the original descriptions, positions for 1800, but no sketches. Actually, there is only one nebula above δ Cet: the 11.6 mag galaxy NGC 1032, seen first (II 5). At ½° above the star there is only a 10th mag star which Herschel must have taken for a "very small nebula".346 Curiously, a third nebula was seen in sweep 47, not recorded in *Sweeps No. 1* (which should be the primary source) and *Sweep*

Records No. 1, but given in *Journal No. 7* (on the page following sweep 47) and *Fixt Stars Vol. 5* (on the page following sweep 49). We read in the latter: "Nebula, ¾ degree n following δ Ceti, in a line parallel to γ and α Ceti; finder and telescope sketches are given." The object is the 10.6 mag galaxy NGC 1055, later catalogued as I 1, Herschel's first object of the 1st class, 'bright nebulae'.[347]

The night of 18 December was exceptional, not only because it was Caroline's debut as assistant. After showing James Lind the "new nebula or comet" (NGC 596 in Cetus), found five days earlier, William made six sweeps (46–51), starting at 7:22 pm in Pisces. Then he visited Cetus, Orion, Puppis, Hydra and Leo, ranging over nearly 9^h in right ascension. Sweeping ended the next morning at 4:23 am. Since the telescope was then oriented towards Leo, he tried a previously unobserved pair of nebulae: M 95 and M 96, culminating at 4:45 am.[348] We read: "[the 20-ft] will not resolve them; there seems however to be in each of them an irregular, lengthened spot near the middle which I suspect to be 3 or 4 pretty large stars. The moon & day light interfere, perhaps a very fine dark night will resolve them."[349] The total observing time in the very clear, cold night was about six hours, thus William 'rested' for three hours. The time intervals between the six sweeps range from 12 to 61 minutes (with a mean of 40 minutes). In short intervals, he probably stayed at the gallery to prepare the next sweep. For a longer break, he climbed down and visited Caroline in her room. Here he checked the notes written by Caroline, added some remarks and, of course, warmed up and strengthened himself with food and drinks. We know from a visitor (see section 2.3.2), that "Herschel observed all through the night, except that he recovered a few minutes every 4 or 3 hours, going back and forth in the mentioned room."

However, when joining his sister, William was exposed to candlelight. This caused a loss of dark adaptation, as mentioned on 13 April 1784. After sweep 191, he rested for about half an hour before the next observing session started. He wrote: "I see a whitish nebulosity in the field owing to my having been in the light." But only five minutes later, he was able to discover a 12.5 mag nebula, NGC 5645 (II 150) in Virgo. This happened several times, as after a

two hour break in the night of 24 April: “The whitish nebulosity from having been in the light is very strong.” Then we read: “The whitish nebulosity is perfectly gone. It seems that it lasted about half an hour that I had been looking at white paper a good while, being employed in writing.” Of course, William took the breaks to take notes, because only brief information could be transmitted to Caroline by simply calling.

Sweep 48 was the longest so far, lasting 2.3 hours. It brought a “cluster of very small stars not very rich” in Monoceros, following 18 Mon by 11^m. Because there still was no PD, only the range due to the sweep breadth of 1.25° was given. The object was not entered into Herschel’s catalogues, but it was added as VIII 1B by John in the *Slough Catalogue*[350] and later catalogued by Dreyer as NGC 2319.[351] However, there is no cluster in the area; it is likely that William has noticed the small star group, shown in Figure 2-16.

Figure 2-16: This nice star group probably is Herschel's 'cluster of very small stars', seen in Monocerotis on 18 December 1783; it was catalogued by John as VIII 1B (NGC 2319).

In sweep 49, Herschel saw "south following 6 Navis [6 Pup] a cluster of stars towards 16 Navis". This is the 9.6 mag open cluster NGC 2479, located about 2° northeast of NGC 2509, found 15 days earlier in sweep 35. The object was not catalogued until a second observation was made in sweep 934 (4 March 1790). Not noticing the earlier one, it got the designation VII 58. In sweep 50, Herschel found "a pretty large star not marked in Flamst[eed's catalogue] of 6th or 7th magnitude". The star is in Hydra, but the place was too rough for an identification. Such 'unknown stars' were later marked 'U' (with superscript number) by Caroline in the *Sweep Records*; we have U^1 here.[352]

The new sweep method was working well. In the next night (19 December), which again was very clear, eight sweeps were made (52–59). They lasted over 11.75 hours (total observing time 6.6 hours) and brought six discoveries. In sweep 54, Herschel saw "three nebulas" in southern Taurus (near the border to Eridanus), "two nebulas close together" and a third to the north (all within 15'). This was Herschel's first case of a non-singular nebula – it was actually a triple, though only two objects appeared in a single field (Figure 2-17). This is the galaxy trio NGC 1587 (II 8), NGC 1588 (II 9) and NGC 1589 (II 7). The first two are separated by only 56" ("two nebulae close together"); see Table 2-28.

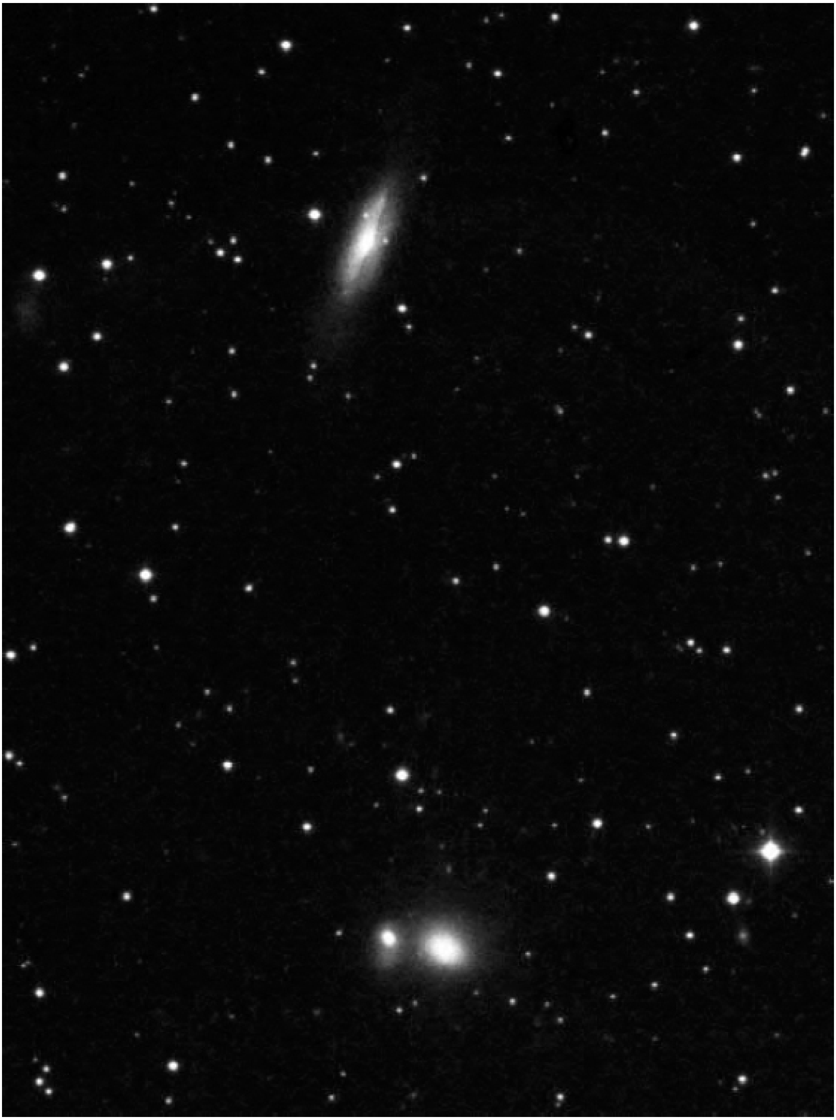


Figure 2-17: Herschel’s first non-singular nebula was actually a triple, found on 19 December 1783 in southern Taurus. It consists of the close pair NGC 1587/88 and, 12' north, the 11.8 mag galaxy NGC 1589.

The night saw still another premiere (in sweep 55): the first ‘star gage’, counting the number of stars in the field of view. This method played a fundamental role in Herschel’s study of the Milky

Way structure (see section 4.1).

Sweep 57 offers another typical example of Herschel's method to determine positions by sketches of the finder and telescope view (Figure 2-18).[353] The object, discovered in Cancer, is described as: "Nebula. The star m is about 2½ degrees north following ω Hydrae. It appears like a comet, with a nucleus. It forms in the telescope an equilateral triangle with two small stars. Not visible in the finder." This is the 10.1 mag face-on galaxy NGC 2775 (I 2).[354] A double nebula was found in sweep 58 and sketched: NGC 3166/69 (I 3/4) in Sextans, 8' apart. In this sweep Herschel counted the stars in two fields (located in Monoceros), giving 60 to 70 stars and 77 stars, respectively.

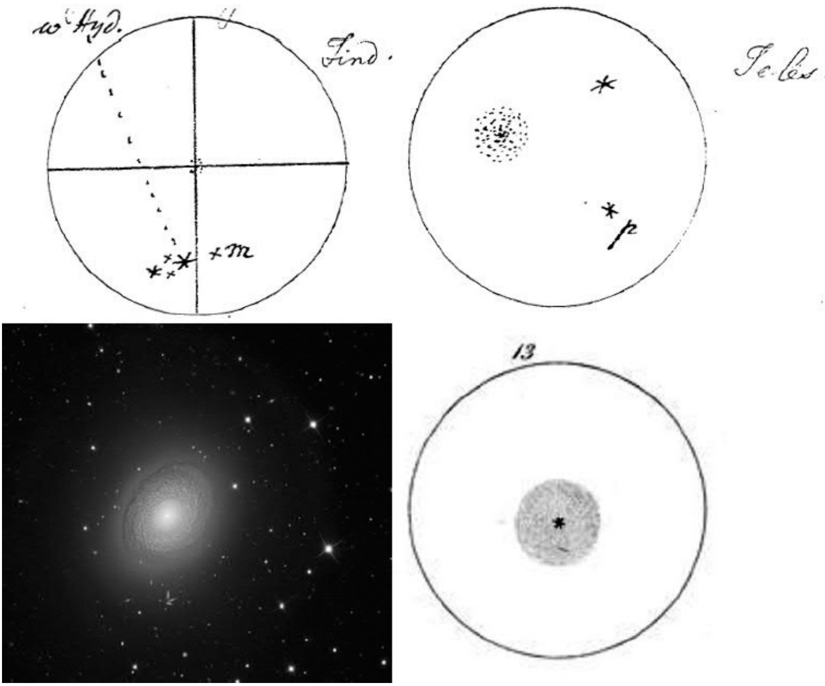


Figure 2-18: Herschel's 'comet with a nucleus' in Cancer, found on 19 December 1783, is the galaxy NGC 2775. Lower right: rendered version, published in 1784.

The record of sweep 59 is followed by a memorandum ('Mem.') about the standard eye-piece used at the 18.7-inch reflector: "Focus

of the sweeping glass 1,53 [inches], aperture 1,01, diameter 1,2, power about 157 times. I use no diaphragm to limit the field of view [15']." Herschel possessed two identical eye-pieces (probably of the standard power 157). They were interchanged, for instance, in case of dew. It is most likely that the eye-pieces were mounted on a simple slide device.[355] The focus was always adjusted by a star, because a nebula was not suitable. However, Herschel used a special method when counting stars ('star gage'): "I adapted the focus of the eye glass to the edges when I counted the stars near the circumference and to the center when I counted those near the middle."[356] This implies that Herschel's standard eye-piece did not produce a sharp image over the entire field of view.

Herschel wrote about this matter:

I make every star pass three times through; once on the preceding side where it is not distinct; once through the middle where it is perfectly defined; and once through the following edge where again it appears distorted by the edge of the lens. I find this much safer than limiting the field to only the distinct part. I have two glasses of the same focus & aperture while I am looking I whipe [wipe] the vacant one of the dew or moisture which glasses continually gather; then I substitute the clean glass into the place of the one that is in use, which in its turn again is preparing while the other contracts moisture. I find the answer extraordinary well.

The method of repeated passes implies that Herschel moved the tube to the west by several fields of view. This is the 'side motion' (Figure 2-5), allowing to track an object for a sufficient time to study and report its features. Caroline wrote: "The long screw-bar gives a side motion to the telescope which enables the observer to follow a star for a considerable time, without displacing the telescope from the meridional situation." Obviously, the tracking was controlled by the observer. After the displacement, the tube must be pushed back to the meridian. An iron plate at the eastern side of the tube prevented any further motion.[357]

In sweep 61 (21 December), Herschel saw "an almost invisibly faint nebula" in Cetus. This is the 12.9 mag galaxy NGC 867 (III 2), the faintest object viewed so far.

Sweep 67 on 26 December brought an interesting observation:358 “A very curious nebula; it is of the shape of a fan, with a bright point. The outside of it from the head is very neatly determined. There seems to be two or three stars near the head of it”. A telescopic sketch was made, showing the fan-shaped appearance (Figure 2-19).359 The “curious object” is the cometary reflection nebula NGC 2261 in Monoceros, now known as Hubble’s Variable Nebula, due to its changing brightness.360 NGC 2261 (IV 2) is Herschel’s second emission nebula, after finding NGC 1980 (Orion) in 1783 in his third review. It is also the second object of the ‘planetary nebula’ class.

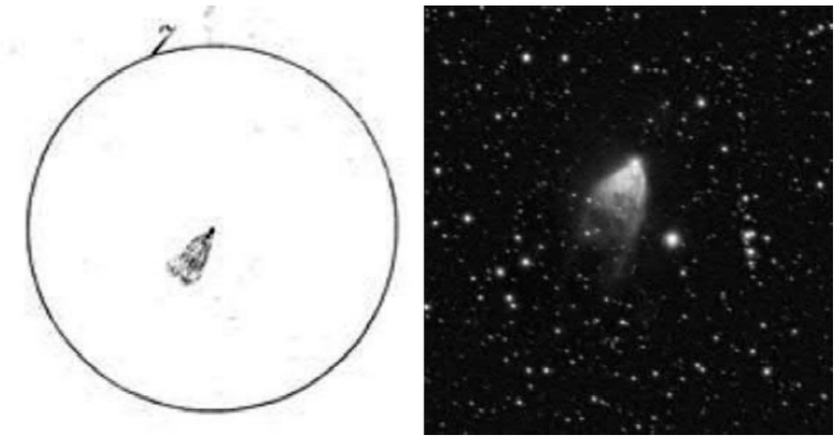


Figure 2-19: Herschel’s ‘curious nebula with the shape of a fan’ in Monoceros, found on 26 December 1783. This is Hubble’s Variable Nebula NGC 2261 (IV 2), illuminated by the variable star R Mon at the top.

On 29 December, the galaxy NGC 1032, ¾° north of δ Cet was observed again (no sweep was made). Christmas Eve brought a curious situation. Two nebulae were discovered, which were not catalogued instantly. In sweep 62, Herschel saw an “exceedingly faint nebula” about a degree northwest of γ Peg; 3 finder sketches and one at the telescope were made. The object is the galaxy NGC 14. It remained uncatalogued until it was rediscovered in sweep 590 on 18 September 1786 (a hint about the former observation is given). The object eventually appeared as II 591 in the second catalogue. In the next sweep (63) a duplication happened, when

Herschel found a “nebula north preceding 17 Ceti”. Unfortunately, in the *Fixt Stars* the record is placed below ‘67 sweep’, which was not reckoned due to haziness (the sweep number was reused on the 26th). Again, three finder sketches and the telescopic view are shown. The object is the galaxy NGC 217, located 52' northwest of φ^1 (17) Cet. It was rediscovered in sweep 479 (28 November 1785), giving no hint about the former observation, and entered as II 480 in the second catalogue.

2.1.5. Sidereal time and Caroline’s first zone catalogue of Flamsteed stars

Late December 1783 brought another innovation, concerning the determination of position. When starting sweep 62 on the 24th, Herschel noted ‘Sydereal time’. From now on sideral time (ST) replaced Greenwich Mean Time (GMT).[361] The new sidereal clock, equipped with a pendulum, was Alexander’s work. In 1786, William wrote:[362]

In about half a dozen sweeps, done according to this new way, I found that the stars of Flamsteed’s Catalogue entered nearly at the time they were expected; this suggested the possibility of converting my telescope into a transit instrument. By way of trial, Dec. 18, 1783, I began to use a watch, and noted the nearest minute; and, this succeeding, Dec. 24, a sidereal time-piece was introduced.

Sidereal time, corresponding to the given GMT on a certain date, can be easily determined: it is equal to the right ascension (AR) of an object when passing the meridian (culmination) at the given time. For instance, at 24 December 1783, 11:00 pm GMT, the meridian (azimuth 180°) was crossed by all objects with AR $5^h\ 18^m\ 34^s$; this is ST. Due to the motion of the Earth around the Sun the relation varies from day to day; 24 hours later we get ST $= 5^h\ 22^m\ 16^s$. This is the known time shift of about four minutes per day. Herschel used the reverse situation to determine the position of an object. A clock showing ST and a telescope, exactly oriented in the meridian measures an object’s AR simply by reading the time when the object passes the centre of the field of view. This is exactly how a transit instrument (meridian circle) works.

However, in Herschel's case things are not that easy. There are two problems. The first concerns the equinox. If the telescope was correctly set to the meridian, one would expect that ST equals the AR of the culminating star as given in the *British Catalogue*. But this is not quite true, because the positions are given for 1690, but sidereal time refers to the equinox of the date! The second problem is due to the telescope setting. Due to Herschel's rough mounting (compared to a precision instrument, like the meridian circle), the south direction was never set exactly. This means that the measured AR does not match the correct value (α). The difference $\Delta\alpha$ can be measured by a star of known right ascension, taken from the *British Catalogue*.[363] The sidereal time is read, when the reference star passes the (imaginary) meridian line in the middle of the field of view. Comparing it with the catalogue position, $\Delta\alpha$ is known. It includes all errors (setting, equinox) and can then be applied to every object whose ST had been noted during the sweep. Then the true right ascension is AR = ST + $\Delta\alpha$. For instance, sweep 62 brought (per Herschel) $\Delta\alpha = -1^m\ 46^s$.

In the period leading to Herschel's first catalogue of nebulae and star clusters, there often was a lack of suitable reference stars, especially in far northern or southern constellations. Occasionally, in nights with several sweeps, ranging in total over several hours of AR, a star was chosen which had a great distance to the observed objects. This can cause less precise positions. Table 2-7 shows all cases with distances greater than 15°. 23 January 1784 shows an extreme case of about 30° (49 Leo, 31 Boo); it caused great trouble involving M 49 and the neighbouring nebulae (see section 2.2.1).

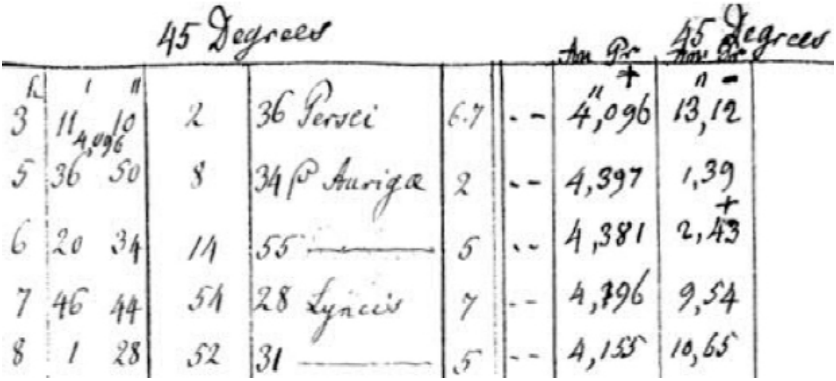
Star	V*	H	Dist (°)	Sw	Date	NGC	Con	V	Type	Remarks
49 Leo	5.7	I 7	31.3	105	23 Jan. 1784	4472	Vir	8.4	Gx	
31 Boo	4.9	II 20	29.4	105	23 Jan. 1784	4612	Vir	11.5	Gx	near M 49
ε PsA	4.2	V 1	28.7	8	30 Oct. 1783	253	Scl	7.2	Gx	Sculptor Galaxy
43 Sgr	5.0	I 48	27.2	230	18 Jun. 1784	6356	Oph	8.2	GC	very dense; near M 9
75 Leo	5.2	V 3	26.0	123	24 Jan. 1784	4910	Vir		NF	sketch
63 Sgr	5.7	VIII 15	25.3	238	15 Jul. 1784	6604	Ser	6.5	OC	near M 16
75 Leo	5.2	II 24	24.2	122	24 Jan. 1784	4772	Vir	11.0	Gx	
47 Psc	5.1	III 202	20.2	290	15 Oct. 1784	7468	Peg	13.7	Gx	
31 Boo	4.9	II 22	19.8	108	23 Jan. 1784	5106	Vir	13.9	Gx	
47 Psc	5.1	III 203	18.7	290	15 Oct. 1784	7497	Peg	12.2	Gx	
ζ Cet	3.7	II 285	18.4	355	10 Jan. 1785	1208	Eri	12.3	Gx	
α Ser	2.6	II 150	18.2	192	13 Apr. 1784	5645	Vir	12.5	Gx	
ι Lep	4.4	VII 3	17.7	136	8 Feb. 1784	1498	Eri		*3	
75 Leo	5.2	II 23	17.5	119	24 Jan. 1784	4420	Vir	12.1	Gx	
19 Pup	4.7	IV 25	16.4	363	31 Jan. 1785	2327	CMa		EN	
υ Cyg	4.4	III 166	16.3	269	13 Sep. 1784	7335	Peg	13.3	Gx	
[6 Crt]	5.2	III 289	16.3	382	10 Mar. 1785	2983	Hya	11.8	Gx	not in BC
υ Cyg	4.4	I 53	16.3	258	6 Sep.1784	7331	Peg	9.5	Gx	
47 Psc	5.1	II 250	16.1	290	15 Oct. 1784	7625	Peg	12.1	Gx	
[6 Crt]	5.2	II 311	16.1	382	10 Mar. 1785	2986	Hya	10.8	Gx	not in BC
ρ Pup	2.8	III 242	15.7	326	20 Nov. 1784	2815	Hya	11.9	Gx	
δ CMa	1.8	II 264	15.5	322	17 Nov. 1784	2139	Lep	11.6	Gx	

Table 2-7: Reference stars, taken from the *British Catalogue* (BC), showing a distance of more than 15° to the discovered objects (taken form Herschel's first catalogue); order = decreasing distance; 6 Crt was not correctly identified by Caroline.

The reference to the *British Catalogue* is essential. Flamsteed arranged the stars by constellation; within they are ordered by increasing right ascension (in degrees). The second coordinate is polar distance (PD), the complement to declination (δ).[364] The catalogue was perfect for the third star review, when the Flamsteed stars were inspected.[365] But it was not suited for sweeping, when zones of constant declination (polar distance) were observed. Thus, a rearrangement of the *British Catalogue* according to PD was needed for practical use.

This was essentially Caroline's job, being already familiar with Flamsteed's work. The period when it was done, follows from a note in her autobiography:[366] "When Flamsteed's Catalogue was brought into zones in 1783 it was only taken up at 45° from the Pole. The apparatus not being then ready for sweeping in the zenith." Caroline's work might have been done in December; the result is titled 'Flamsteed's Catalogue brought into zones'.[367] The table gives for every star: right ascension (AR) and polar distance (PD) for 1690, designation (Bayer letter, Herschel's 'Flamsteed number'),

magnitude, annual precession for both coordinates. The stars are ordered in PD zones of 1° breadth, starting with 45° and ending with 126° (which is $\delta = +45°$ to -36°). Within each zone, the stars are ordered by AR. The first star in Caroline's table is 36 Per (Figure 2-20). The line starts with AR (^{h}) and PD (°). The number (6.7) means 6 to 7 mag.



h	'	"	°	45 Degrees			An. Pr. +	45 Degrees −
3	11	10 (4,096)	2	36 Persei	6.7	--	4,096	13,12
5	36	50	8	34 β Aurigæ	2	--	4,397	1,39
6	20	34	14	55 ——	5	--	4,381	+ 2,43
7	46	44	54	28 Lyncis	7	--	4,196	9,54
8	1	28	52	31 ——	5	--	4,155	10,65

Figure 2-20: First entries in Caroline's table 'Flamsteed's Catalogue brought into zones' (see text). Note that the AR minute (^{m}) is written as '.

Finally, we have the annual precession in AR and PD. To get the listed values, Caroline had to do some calculation, which she made perfectly. The *British Catalogue* gives the precession for 72 years, the time for the equinox to advance by 1° (360° in 26,000 years equals 1° in 72 years). Because Flamsteed measured both AR and PD in °, the catalogued precession is given in ' ". But Caroline's AR is in ^{h}, thus the annual precession is given in ^{s}. The value for the PD precession is (as usual) in ". If we set the decimal numbers of Flamsteed's precession for 72 years = x and Caroline's annual precession = y, one must calculate:

annual precession in AR: $y = 60 \cdot x/(72 \cdot 15) = x/18$

annual precession in PD: $y = 60 \cdot x/72 = x/1.2$

However, there is another version of her table (made together with the former), listing stars between PD 45° and 124° for 1690, but not giving the annual precision.[368] With that table, it was easy to say

which Flamsteed stars are in a certain sweep zone, an essential information for planning and monitoring a sweep. In July 1785, Caroline made a new version, titled ‘Flamsteed’s Catalogue second copy 0° and 126° inclusive’ (see section 2.3.5).

With Caroline’s zone table, the AR could be determined by reference stars. But what about PD? Another mechanical improvement provided much better values for this coordinate. The new device, called ‘PD index’, was first applied on 30 December 1783:

An improvement in my apparatus gives me the difference of polar distance in a rough way which may be of considerable use. A scale of inches affixed to a place behind the rope which lifts up the telescope serves to give me the difference between any one particular situation and that of a known star before observed. At every altitude I sweep I settle the value of arch of two degrees. For instance this evening I found my telescope being raised two degrees occasioned the string to pass over a space of 24 inches; therefore every inch is equal to five minutes. In other altitudes the value of two degrees in inches is different but by a proper table I can always know what answers to an inch on setting the number of inches the rope passes through to raise the tube 2 degrees. The numbers of minutes is always to be understood from the position I begin with upwards; except the sign minus should be affixed to them it is a sign that they are to count downwards.

When an object passed the meridian, Caroline now registered the time, read from the sidereal clock, and the PD index. The zero of the scale (upper PD limit) and the conversion factor from inches to degrees (varying with altitude) were determined by observing a known star in the finder. The result are relative values for the AR and PD for all measured objects. Usually, a Flamsteed star was among them. Due to the known coordinates, the relative positions of all other objects could be transformed into absolute positions, i.e. coordinates for 1690, the equinox of the *British Catalogue*. The new method brought much better positions.[369] Sketches and textual descriptions, formerly used, became obsolete.

What was observed on 30 December (sweep 68)? Herschel discovered a “cluster of exceedingly small stars, very much

compressed" in Gemini.[370] It was referenced by γ Gem, crossing the field centre at 6^h 24' (ST). The rope scale showed 4 inches = 20'. The cluster passed at 6^h 43' with 24 inches = 2°. Thus, it is 19^m east and 1° 40' north of γ Gem. Taking the star position from the *British Catalogue*, Herschel derived "AR 6 40¾ PD 71 43" (1690). The correct value is AR 6 37.0, PD 71 40. The major error is in AR, due to poor timing, whereas the 'PD index' worked pretty well.

From 13 December (sweep 42) to the end of 1783 (sweep 75), Herschel discovered 20 nebulae and star clusters. This proves that the new method, technical innovations, and of course Caroline's knowledgeable support brought more comfort and efficiency. On average, a sweep lasted 45 minutes with a breadth of 1.25°.

2.1.6. The first deep-sky catalogue and a preliminary classification

Occasionally, objects were seen again in another sweep: NGC 2509 (sweeps 35 & 49), NGC 157 (42 & 66), NGC 596 (44 & 60) and NGC 1032 (47 & 62). Of course, the identification of double observations required a good accounting. This issue was in the reliable hands of Caroline. In late December, she created the necessary table to control all discoveries, titled 'Index to new Nebulas & Clusters of Stars' (Figure 2-21).[371]

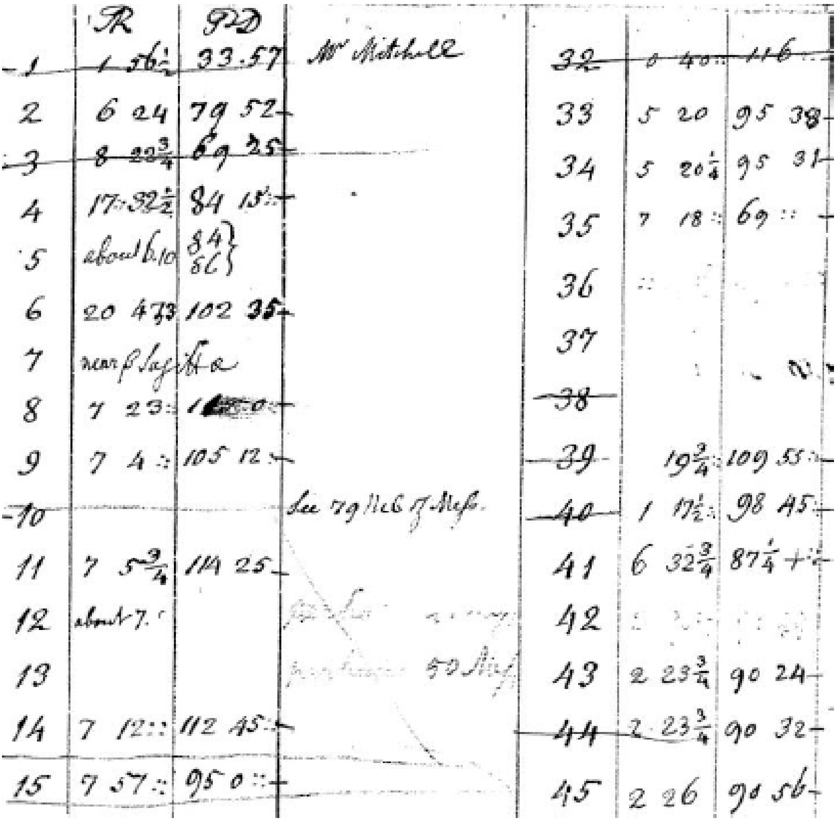


Figure 2-21: Initial part of Caroline's first list of nebulae and star clusters, found by her brother.

This actually is the first catalogue of non-stellar Herschel objects. However, the presented data are pretty poor, giving only a running number and a rough position (AR, PD). For some numbers, there is no entry. Because there is no explanation, the interpretation of the data (positions, order, objects) is difficult. Some detective work yields: the positions are for 1690 and the entries are sorted by date (like the *Messier Catalogue*). Nevertheless, all objects could be identified.

Despite the lack of quality, Caroline's table gives some insight about recording the observations. A revised version is presented in Table 2-8. It contains the first 63 objects, found until the end of 1783. Those numbered 1 to 24 were seen prior to sweeping.

No.	Object	Date	Type	Con	Δ (')	H	Remarks
~~1~~	χ Per	2 Oct. 1780	OC	Per	33	VI 34	'Mr Mitchell'
2	NGC 2264	15 Feb. 1781	OC	Mon	0	VIII 5	15 Mon
~~3~~	M 44	21 Feb. 1781	OC	Cnc	10		Praesepe, No. 21
4	IC 4665	15 Jul. 1781	OC	Oph	22		CH, No. 18
5	NGC 2244	22 Oct. 1781	OC	Mon	88	VII 2	12 Mon, No. 25
6	NGC 7009	7 Sep. 1782	PN	Aqr	2	IV 1	
7	M 71	4 Nov. 1782	GC	Sge	-		
8	M 93	26 Feb. 1783	OC	Aur	13	VIII 71	6 Nov. 1782; CH, No. 16
9	NGC 2360	26 Feb. 1783	OC	CMa	8	VII 12	CH
~~10~~	M 79	4 Mar. 1783	GC	Lep	-		
11	NGC 2362	4 Mar. 1783	OC	CMa	2	VII 17	around τ CMa
12	M 46	4 Mar. 1783	OC	Pup	-		CH
13	NGC 2311	4 Mar. 1783	OC	Mon	-	VIII 60	CH
14	29 CMa	4 Mar. 1783	SP	CMa	30		
15	M 48	8 Mar. 1783	OC	Hya	23	VI 22	CH
16	M 93	2 Apr. 1783	OC	Pup	70		26 Feb. 1783; CH, Journal, No. 8
17	NGC 6633	31 Jul. 1783	OC	Oph	52	VIII 72	
18	IC 4665	31 Jul. 1783	OC	Oph	-		16 Jul. 1783; CH, No. 4
	NGC 5195	17 Sep 1783	Gx	CVn	11	I 186	
19	NGC 752	24 Aug. 1783	OC	And	41	VII 32	CH
20	NGC 253	23 Sep. 1783	Gx	Scl	118	V 1	CH, No. 32
~~21~~	M 44	28 Sep. 1783	OC	Cnc	92		21 Feb. 1781; Praesepe, No. 33
22	NGC 6866	16 Oct. 1783	OC	Cyg	30	VII 59	CH
23	NGC 205	24 Oct. 1783	Gx	And	23	V 18	CH
24	NGC 7184	28 Oct. 1783	Gx	Aqr		II 1	position of NGC 7505 (see 31)
25	NGC 2244	29 Oct. 1783	OC	Mon	3	VII 2	23 Oct. 1781; E, 12 Mon, No. 5
26	NGC 2232	29 Oct. 1783	OC	Mon	14	VIII 25	5 Dec. 1779; E; Figure 2-57
27	-	29 Oct. 1783	*Grp	Gem	-		E, near ξ Gem
28	-	29 Oct. 1783	*Grp	Gem	-		E, near ξ Gem
29	-	29 Oct. 1783	*Grp	Ari	5		E, around ξ Ari
30	-	29 Oct. 1783	*Grp	Aur	2		E, around ϕ Aur, OC Stock 8?
31	NGC 7507	30 Oct. 1783	Gx	Scl	44	II 2	sw 7
~~32~~	NGC 253	30 Oct. 1783	Gx	Scl	120	V 1	sw 20; CH 23 Sep. 1783
33	-	3 Nov. 1783	EN	Ori	7	III 1	part of M 42, sw 15
34	M 43	3 Nov. 1783	EN	Ori	7		sw 15
35	NGC 2420	19 Nov. 1783	OC	Gem	80	VI 1	sw 26
36	NGC 2509	3 Dec. 1783	OC	Pup	-	VIII 1	sw 35
37	NGC 2432	3 Dec. 1783	OC	Pup	-	VI 36	sw 35
~~38~~	NGC 2421	3 Dec. 1783	OC	Pup	-	VII 67	sw 35
~~39~~	NGC 157	13 Dec. 1783	Gx	Cet	590	II 3	PD error of 10°, sw 42
~~40~~	NGC 596	13 Dec. 1783	Gx	Cet	8	II 4	sw 44
41	NGC 2301	18 Dec. 1783	OC	Mon	124	VII 38	sw 48
42	NGC 2479	18 Dec. 1783	OC	Pup	-	VII 58	sw 48
43	NGC 1032	18 Dec. 1783	Gx	Cet	10	II 5	sw 47
~~44~~	-	18 Dec. 1783	*	Cet	4	II 6	sw 47
45	NGC 1055	18 Dec. 1783	Gx	Cet	2	I 1	sw 47; near M 77
46	NGC 1589	19 Dec. 1783	Gx	Tau	9	II 7	sw 54
47	NGC 1587	19 Dec. 1783	Gx	Tau	3	II 8	sw 54

No.	Object	Date	Type	Con	Δ (')	H	Remarks
48	NGC 1588	19 Dec. 1783	Gx	Tau	3	II 9	sw 54
49	NGC 2775	19 Dec. 1783	Gx	CNC	75	I 2	sw 57, sketch, Figure 2-18
50	NGC 3166	19 Dec. 1783	Gx	Sex	142	I 3	sw 58
51	NGC 3169	19 Dec. 1783	Gx	Sex	142	I 4	sw 58, Herschel W. (1811: Fig. 22)
52	NGC 867	21 Dec. 1783	Gx	Cet	104	III 2	sw 61
53	NGC 7800	24 Dec. 1783	Gx	Peg	24	II 10	sw 62
54	NGC 2254	26 Dec. 1783	OC	Mon	900	VII 22	AR error 1^h, sw 67
55	NGC 2261	26 Dec. 1783	RN	Mon	900	IV 2	AR error 1^h, sw 67; Figure 2-19
56	NGC 2251	26 Dec. 1783	OC	Mon	900	VIII 3	AR error 1^h, sw 67
57	NGC 2304	26 Dec. 1783	OC	Gem	52	VI 2	sw 68
58	NGC 3655	30 Dec. 1783	Gx	Leo	6	I 5	sw 71
59	NGC 3853	30 Dec. 1783	Gx	Leo	47		sw 72, near β Leo, no class!
60	NGC 4028	30 Dec. 1783	Gx	Com	68	III 3	sw 72
61	M 98	30 Dec. 1783	Gx	Com	15		sw 73
62	NGC 4237	30 Dec. 1783	Gx	Com	35	II 11	sw 73; near M 98
63	NGC 4651	30 Dec. 1783	Gx	Com	40	II 12	sw 74; last object of 1783

Table 2-8: The first 63 entries of Caroline's catalogue (revised version). No. = Caroline's number; type: * = star, *Grp = star group; Δ = difference between Herschel's and actual place; H = later class designation; remarks: CH = Caroline, E = naked eye, sw = sweep (more information in the text).

The remark 'Mr. Mitchell' refers to John Mitchell's publication of 1767, where the bright open clusters Pleiades, Praesepe and 'ε Persei' (Double Cluster) are treated in the context of parallax.[372] Caroline collected all supposedly non-stellar objects from the *Journal* and *Fixt Stars*. This was not an easy task, because some were hidden in the stack of notes. She ordered the objects by the date of first appearance (NGC 5195 was later added with no number). However, not all dates are correct; in some cases, an earlier observation was missed (the revised date is given in 'Remarks'). Caroline overlooked 12 objects of which nine are true discoveries of William (Table 1-18).[373] She later deleted some objects (like 10, crossed out in the original). However, this is not justified for numbers 38, 39, 40 and 44. On the other hand, there are cases which must be deleted. Four objects are identified with a star pattern (asterism), one is a star. M 44, M 93, NGC 253, NGC 2244 and IC 4556 appear twice. This is due to poor positions; their quality can be seen in column 'Δ' (cases in which no position was given are marked '-'). All positions for NGC 253 are bad, due to the lack of reference stars in northern Sculptor. For NGC 7184 (no. 24) the position of NGC 7507 (no. 31) is given, though not exact. In the

case of NGC 157, the place is 10° too far south and for NGC 2251/54/61 the AR is 1^h too small. Nevertheless, many positions are pretty good, though often only estimated. Some objects were taken from William's collection of naked-eye views (beside sweep 1; see Table 2-4). The list contains the objects found in sweeps 7–73, made until 30 December 1783. M 43 was not identified; the other nebula (III 1) is only a small part of the Orion Nebula. Objects seen also by Caroline are marked 'CH' (see Table 1-21). In most cases she is the discoverer and William only confirmed her observation. The larger portion of the objects appear in Herschel's published catalogues with their class designation (H).[374]

The objects observed in the sweeps of 1783 have declinations between -28° and +21°, with a mean of 0° (celestial equator). Thus, the tube elevation in the meridian position ranged between 11° and 60° (mean 39°). Obviously, this was due to the shaky gallery. Herschel felt himself insecure at higher elevations. When later sitting on a chair at the side of the tube, observing was much safer.

Caroline continued her list up to no. 742, an object seen on 20 December 1784 in sweep 349. This is the 11th mag galaxy NGC 4179 (I 9) in Virgo. Although her numbers 739 to 741 refer to new objects in Virgo, the last number does not. I 9 was already discovered on 24 January 1784 in sweep 118. This shows that her table did not recognize double entries. Later, Caroline became aware of this fact and created a revised table, showing new numbers. It would finally contain the magical number of 1000 objects – the signal to publish the discovered nebulae and star clusters.

Caroline's table and the recorded descriptions were used for a first classification. Of course, the trial was made under the supervision of her brother. The table immediately follows her first catalogue (Figure 2-22).[375]

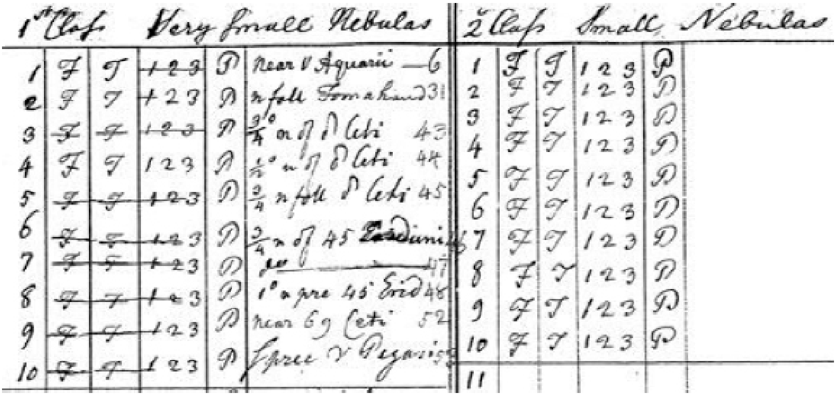


Figure 2-22: The first two classes of Caroline's trial classification. The first entry is NGC 7009 in Aquarius (no. 6 in her table).

The non-stellar objects are divided into eight classes (Table 2-9). The entries in each class are numbered, according to the sequence given in her catalogue. For every object, the place relative to a star is given. The highest number is 57; this is the galaxy NGC 2304 in Gemini, found on 26 December 1783. The last discovered object is the 2nd entry in class VI. The date marks the time when the siblings developed the classification scheme. The table is problematic: three of Caroline's own objects are added (NGC 189, NGC 225 and NGC 7789), others are missing. However, the two observations of NGC 253 by William are now identified.

Class (trial)	Object type	Entries
1st	very small nebulas	11
2nd	small nebulas	-
3rd	small, cometic nebulas	3
4th	large nebulas	6
5th	large cometic nebulas	1
6th	resolvable nebulas or clusters of very minute stars	2
7th	clusters of close stars	10
8th	clusters of scattered stars	26

Table 2-9: Caroline's first classification scheme, developed in late

December 1783.

Don’t confuse these trial classes with those of the ‘H’ designation (Table 2-8), referring to the final classification scheme, developed for the first published catalogue. H-numbers are commonly treated like ‘catalogue numbers’, though they originally only represent a special order according to object type. The very first catalogue number is the one introduced in the first column of Caroline’s first catalogue (Figure 2-21). It was called ‘General number’ (GN). In contrast to the ‘H-number’, it was never published. The ‘General number’ appears in the revised sweep records and in many documents. It is comparable to the Messier number (M); both relate to the discovery date (in contrast to NGC-numbers, based on right ascension). Due to identities or additions in the catalogue, numbers were often changed (which is also true for H-numbers). In a note written during the revision of the sweep records (below sweep 673), Caroline explained the difference between class designation and ‘General number’:

In transcribing these observations, I have often left out the class and number, because when they make their appearance it is generally in an irregular manner; sometimes the general number, and in other places the sweeps are quoted for a reference to a former nebula. But in this work, they have uniformly the number of the general catalogue; and as that catalogue has the classes &c. affixed to the general number; all the particulars of each nebula and cluster will readily be found. But if a class & number, or sweep is mentioned in such a manner, that it cannot with propriety be omitted, I have copied the observations exactly as they stood.

In the period of the 1783 sweeps, eight Messier objects were viewed with the 18.7-inch. Thanks to Caroline’s entries in the *Atlas Coelestis*, their celestial places were visible. She calculated at when an object crossed the meridian. Thus, the observation was a matter of time and elevation.

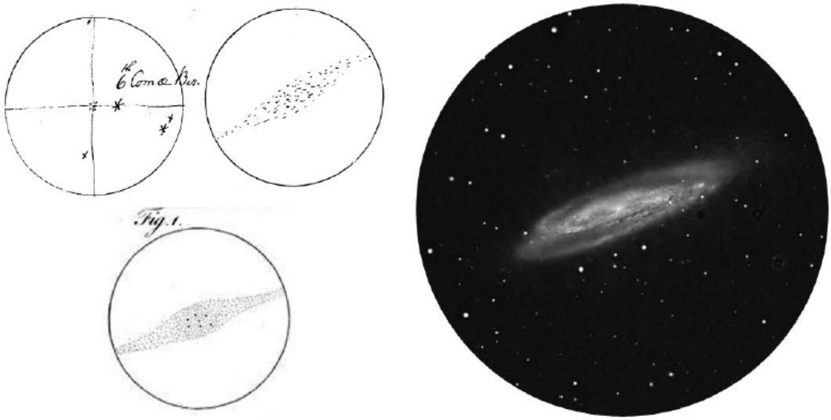


Figure 2-23: M 98 in Coma Berenices. Upper left: finder and telescope views on 30 December 1783; lower left: published sketch (1785); right: modern image with Herschel's field of view (15'). Note that the galaxy does not actually fill the field.

The galaxy M 77 in Cetus was seen on 29 October, and again on 3 November. In the latter night, Herschel also viewed M 42 and for the first time, M 43. On 19 November, the open cluster M 41 in Canis Major was observed. 18 December brought the first view of the galaxy pair M 95 and M 96 in Leo.[376] In the following night, the reflection nebula M 78 in Orion was seen ("two large stars well defined in the nebula"). Another premiere happened on 30 December (sweep 73): the galaxy M 98 in Coma Berenices; the fine sketch shows the elongated nebula with some stars in it (Figure 2-23). Herschel's comment about the "large, extended, fine nebula" is interesting: "It seems to be Messier 98th, but from the description in la Connoissance des temps it appears that Messier has not seen the whole of it, for its feeble branches extend above a quarter of a degree of which no notice is taken." He notes an extent "above a quarter of degree" (25'), thus M 98 exceeds the field of view (15') in his sketch. But he overestimated the size, the galaxy measures only 10' (see Table 5-15). About 2° northeast of M 98, Herschel saw another nebula (II 2 = NGC 4237): "It is pretty large but very feeble. Almost round but not cometic. It is not Messier's for being too feeble it would not be seen by an achromatic of 3½ ft, which I suppose is the maximum of his light." This was another proof that his instrument was superior.

The ‘PD index’ was operational on 30 December (sweep 68). It had a scale with 100 numbers (highest number = smallest PD = highest tube elevation). To get the relative polar distances corresponding to the numbers, two Flamsteed stars were observed in the finder (equipped with crosshairs) during the sweep, showing the maximum PD difference. Because their positions were known from the catalogue, the scale was calibrated. The PD for the top/bottom position of the sweep, the breadth and the number corresponding to 1° were now fixed. The absolute polar distances were eventually determined from the PD of the reference star.

From his first true discovery of a non-stellar object, NGC 2232 on 5 December 1779, until 30 December 1783, we have 40 discoveries. Since Messier had credited 41 of his 103 objects to other observers, Herschel must have believed that his French competitor had found 62 objects. However, a modern analysis of the Messier objects reduces this number to 41; Messier was not aware that 21 of his ‘own’ objects had been discovered earlier by other astronomers. Thus, Herschel could (unknowingly) catch up with his competitor with his next find.

However, Messier’s score could not be reached on 31 December, due to a dramatic accident, happening when the siblings prepared the 20-ft telescope for sweep 76. The first winter at Datchet was an exceptionally cold one, though with a period of very clear nights in December. The weather influenced not only the observer but the instrument as well. Wet air coming from the nearby Thames could cause a covering with ice and frost damage. Herschel worried about the fate of his main mirror. On New Year’s Eve, the thermometer showed a temperature much below zero and snow covered the ground. Caroline pictured the event in her biography:[377]

That my fears of danger and accidents were not wholly imaginary I had an unlucky sample of on the night of the 31st of December. The evening had been cloudy but about 10. o’Clock a few stars became visible, and in the greatest hurry all was got ready for observing. My Brother at the front of the Telescope directing me to make some alteration in the lateral motion which was done by a machinery in which the point of support of the tube and mirror rested (it is describe some where as belonging to the small 20-ft) at each end of

the machine or through was an iron hook such as butchers use for hanging their joints upon, and having to run in the dark on ground covered foot deep with melting snow, I fell on one of these hooks which entered my right leg about 6 inches above the knee, my Brothers call ‘make haste’ I could only answer by a pitiful cry ‘I am hooked’.

He and the workman were instantly with me, but they could not lift me without leaving near 2 oz. of my flesh behind. The workman’s wife was called but was afraid to do anything, and I was obliged to be my own surgeon by applying aquabaseda and trying a kerchief about it for some days; Dr Lind hearing of my accident brought me ointment and lint and told me how to use it. But at the end of six weeks I began to have some fears about my Limb and had Dr Lind’s opinion, who on seeing the wound would found it going on well; but said, if a soldier met with such a hurt he would have been entitled to 6 weeks nursing in a hospital. I had however the comfort to know that my Brother was no loser through this accident, for the remainder of the night was cloudy and several nights afterwards afforded only a few short intervals favourable for sweeping until the 16th of January before there was any necessity for exposing myself for a whole night to the severity of the season.

I could give a pretty long list of accidents which were near proving fatal to my brother as well as myself. To make observations with such large machinery, where all around is in darkness, is not unattended with danger, especially when personal safety is the last thing with which the mind is occupied. Even poor Piazzi did not go home without getting broken shins by falling over a rack-bar, which projects in high altitudes in front of the telescope, when in the hurry the cap had been forgotten to put over it.[378]

2.1.7. Summary of the 1783 sweeps

Table 2-10 gives statistical data of the 1783 sweeps, from no. 1 on 29 October to no. 75 on 30 December. This early period saw the change from horizontal ‘oscillations’ to the vertical ‘sweeping motion’ of the tube. The new method and further improvements of the instrument (bar mechanism, sidereal clock, PD index) and observing technique led to a significant rise of discoveries. The

elevation of the tube was still limited to 60°. Caroline, badly injured on 31 December, began to order the discovered objects using their identity and optical appearance. This led to a first catalogue of nebulae and star clusters, their appearance to a trial classification of the objects. Positions were determined from sketches. The first 'star gages' were made.[379] On 14 November, Herschel saw Mercury for the first time, using the naked eye.

Category	Value	Remarks
number of nights	18	
longest continuous period (days)	2	
longest break (days)	13	
number of sweeps	75	
sweeps per night	4.2	
mean night (h)	5.2	
longest night (h)	11.8	19 Dec. (observing time 6.6 hours)
sweeps per night (maximum)	11	30 Oct.
highest elevation (°)	60	PD 69°, several sweeps
lowest elevation (°)	11	
lowest PD (°)	42	
observed objects	40	
objects per night (mean)	2.2	
sweeps without objects	53	
new objects (all)	30	
uncatalogued objects	2	Table 5-5
re-observed objects	10	
most productive night	18 Dec.	8 objects
objects: first	30 Oct.	NGC 7507 (Gx Scl)
last	30 Dec.	NGC 4651 (Gx Com)
brightest (mag)	7.3	NGC 2251 (OC Mon)
faintest (mag)	12.9	NGC 1588 (Gx Tau)
smallest (")	66	NGC 1588 (Gx Tau)
multiple	2	2 pairs
Messier objects (all)	8	

first observation	4	
first with 20-ft	7	
star gages	2	
vacant places	2	

Table 2-10: Sweep statistics for 1783.

2.2. The record year 1784

The number of events (sweeps, discoveries, etc.) is so large that the year is divided into quarters. In addition, we do not treat them strictly chronologically (as for all later years), but concentrate on different object categories, such as globular clusters, galaxies (especially pairs, trios etc.), globular clusters or Messier objects.

2.2.1. Observing on a chair and the M 49 drama

Sweep 76, which could not take place on 31 December due to Caroline's severe accident, was eventually performed in the windy night of 16 January 1784. Although her wound was still painful, she was at her new place of work. William checked his nebulae near δ Cet (NGC 1032, NGC 1055), finding them in their former places.

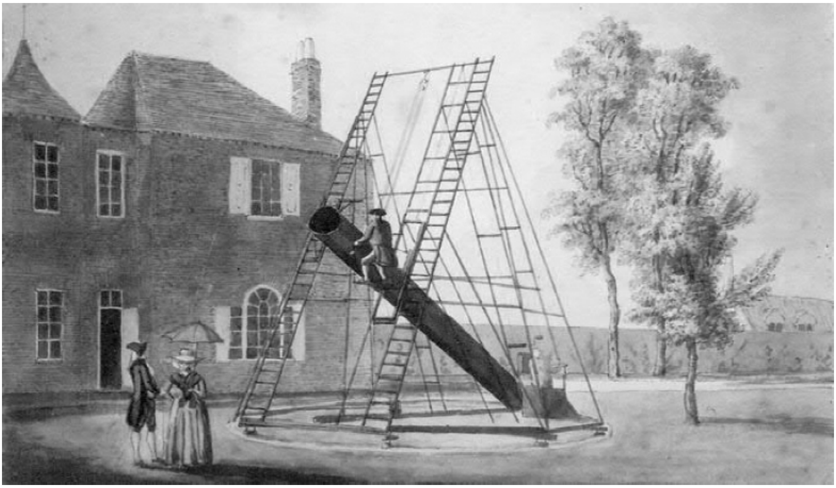


Figure 2-24: The 18.7-inch reflector, erected at Datchet. Herschel is sitting on the chair, accessible from the right ladder. A workman at

the tube base controls the vertical motion. The telescope is placed south of the house (it points to the east). The drawing was made in 1784 by Thomas Rackett (probably in spring, given the leavy appearance of the trees). Note that the quadrant, installed on 24 June 1784 on the framework above the chair, is still missing (compare Figure 2-128).

It is likely that Herschel used the 2-week break in January to change his position at the telescope. This is supported by the observations made that month (see below).[380] Because of the vertical 'sweeping motion', a front gallery was now obsolete. A much better place for the observer was at the side of the tube. Fortunately, we have a nice watercolour, showing the telescope in spring 1784 at Datchet (Figure 2-24).[381] Herschel is sitting – in daylight! – on a chair at the Newtonian focus.[382] It is held by the front part of the ladder-type stand. A workman, located at the base of the tube, controlled the up/down motion and the corresponding chair position by handles.

17 January (sweep 78) brought the first discovery of the new year: NGC 1896 (VIII 4), which is only a star group in Auriga (Figure 2-25). The declination of $+29^\circ$ is interesting: it implies a tube elevation of 68°, significantly above the limit of 1783. Using a shaky gallery might have been too dangerous, especially in winter; a chair would be much safer. This conclusion is supported by two events, happening on 21 & 22 May in sweeps 222 and 223. The former ends at 1:33 am with the discovery of the bright globular cluster NGC 6401 (I 44) in Ophiuchus. Seven minutes later we read "Left off". Then Herschel noted: "I turned my telescope into the milky way near the bow of Sagittarius, notwithstanding the strong daylight I counted 102 stars in the first field of view I fixed upon." The region of the 'star gage' is about 7° east (about 30^m in RA) of the final sweep position. What was used for the turn, the 'side motion', 'lateral motion', or 'round motion'? The 'side motion' is ruled out, because it turns the tube to the west! But the 'lateral motion', used in the early 'oscillations', ranges over 7.5° to both sides of the meridian. In this case the telescope mounting is still oriented to the south, but the tube could be shifted 7° to the east. To follow the eye-piece the observer needed the gallery. Of course, this is an argument against the chair! However, we must recall that

the ‘lateral motion’ was performed by a shift of the tube end at the bottom. There was a screw to move it sideways, like the one used for the ‘small 20-ft’ (Figure 1-10). However, this mechanism was already removed, in the course of the installation of the ‘bar motion’ (it shifts the tube end towards the centre of the peripheral ring to allow a steeper alignment of the telescope).[383] Thus we end up with the ‘round motion’. The azimuthal rotation of the whole instrument was used from the beginning for observations out of the meridian – it needs no gallery! The observation in Sagittarius was such a special matter.

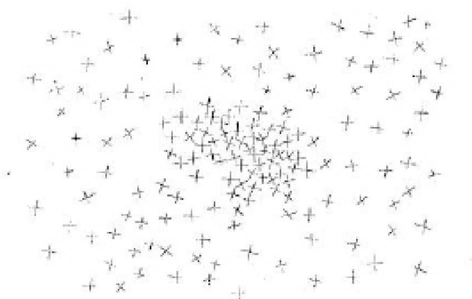


Figure 2-25: The star group NGC 1896 in Auriga, found on 17 January 1784 (sketched on 16 February 1786.[384]

Further support of this conclusion is due to sweep 223, made the next night. Herschel registered the transit 51 Oph at 1:15 am (on the 23rd). Then he noticed “a strong haziness near the horizon”. The telescope had an elevation of 14°. We read: “My sister continued while I rested.” After 16 minutes, William began again, counting stars. During that interval Caroline must have taken his place on the chair. Due to the low altitude, it was a safe job for her. Considering her recent accident, it is unlikely that she would have been willing to stand on an unsafe gallery.

On 18 January, Herschel performed nine sweeps (80–88) over 10.5 hours. With 7.3 hours, the total observing time was incredibly long – and the yield was large. No less than nine non-stellar objects were discovered: six galaxies, two open clusters and a reflection nebula. It all started with NGC 1662 in Orion. The pretty bright open cluster (6.4 mag) was catalogued as VII 1, the first entry of the 7th

class, ‘compressed clusters of small and large stars’. With his 42nd discovery, Herschel had overtaken Messier.[385] In sweep 81 the cometary reflection nebula NGC 2245 (IV 3) in Monoceros was found, another strange object that was put in class IV. Herschel noted: “It is fan shaped, and appears like a star with a faint electric brush on one side of it.” The interesting appearance was illustrated by a sketch (Figure 2-26; see also Figure 2-92 and Table 2-26).[386]

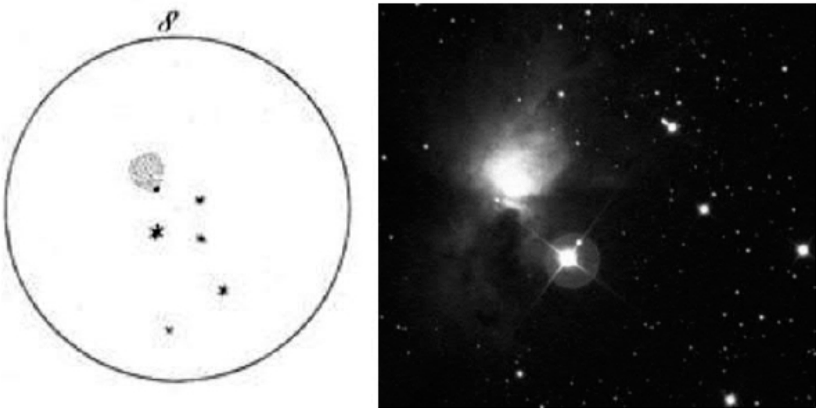


Figure 2-26: The cometary reflection nebula NGC 2245 (IV 3) in Monoceros near a 7.5 mag star was found on 18 January 1784.

The sweep also brought an unexpected rediscovery, the 4.1 mag open cluster NGC 2264: “The 15th Monocerotis is attended by above 30 considerable stars”.[387] Herschel was not aware that he had already found the star cluster with the 6.2-inch in the second review on 15 February 1781 and catalogued it as VIII 5. Much later, in sweep 494 (26 December 1785), he perceived parts of the faint nebulosity in which the cluster is embedded. He catalogued it as ‘large nebula’ V 27. The nice ensemble was again seen in sweep 682 (11 January 1787). Dreyer catalogued both the stars and the nebulosity as NGC 2264. Note that Herschel’s nebulosity is not the famous Cone Nebula! This striking dark feature is 28' south of 15 Mon and visually a very difficult object (Figure 2-27).

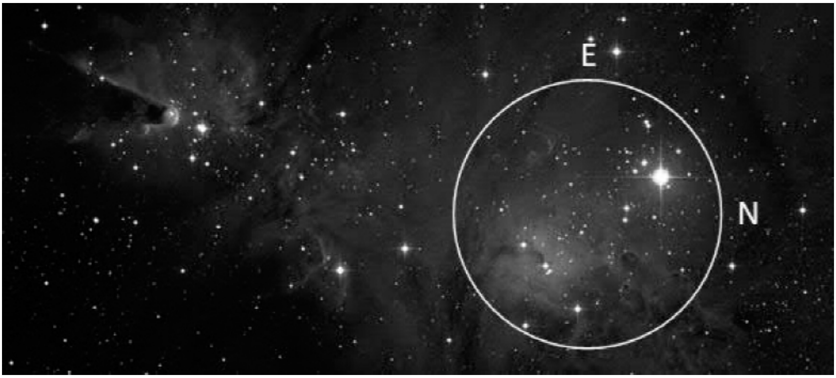


Figure 2-27: The field of view contains 15 Mon (4.7 mag) plus the surrounding open cluster (VIII 5) and the brightest part of the nebulosity (V 27), both catalogued as NGC 2264. The dark Cone Nebula is seen left (south).

On 19 January (sweeps 89 and 90), Herschel suddenly (and for only one night) returned to GMT. Perhaps Alexander's clock was not working properly (there has been a clock problem between sweeps 104 and 105, on 23 January). The sidereal time was estimated from Flamsteed's catalogue. Moreover, Herschel was not satisfied with the PD index. Often a known star was outside the scale or the mechanism was inadequate. In either case, he could not abandon a sketch in order to identify the star, which was a great inconvenience. On the 20th (sweep 91) he noted: "I found the method described 480 [30 December 1783] capable of greater accuracy therefore have introduced smaller divisions and carried them into the room near the clock where they may be read off more exactly." Five days later, Herschel wrote: "My numbers for the PD are now decided differently, and my Zero [of the PD index] is upwards, so that the order of them is now the same with the order of Flamsteed, i.e. the number increase towards the south. I have also enlarged the scale by advancing the point of suspension of the telescope. I shall for the future take as many stars as convenient as the best measure against changes." He has reversed the scale on the PD index, now counting upwards. From this date on, only sketches of the telescopic view were made, the finder view (to fix the position) having become obsolete. Sketches at the eye-piece were meant to illustrate interesting objects. After the end of February, they appear only occasionally.

In the night of 23 January, 17 sweeps were made (95–111), lasting over 12.3 hours! The total observing time was 8.1 hours – this mark was never exceeded. Leaving the telescope at a declination of about 10°, Herschel passed through Cetus, Taurus, Eridanus, Orion, Monoceros, Canis Minor, Hydra, Sextans, Leo, Virgo and Boötes. In sweep 99, he discovered a “small claret coloured star” in Orion, listed as ‘unknown star’ U^{13}. The conspicuous red star is W Ori, located in the western part of the constellation.[388] It was the first ‘garnet star’, found in a sweep. Table 2-11 shows all such objects.

Star	V	B-V	Sw	Date	Description	U	Remarks
W Ori	6.1	3.4	99	23 Jan. 1784	garnet coloured	13	sw 526
RT Cap	8.9	4.0	246	8 Aug. 1784	very deep fine garnet colour	203	J. Herschel’s Ruby Star
χ Cyg	4.4	1.8	258	6 Sep. 1784	beautiful garnet	220	
BL Ori	6.0	2.3	293	15 Oct. 1784	most beautiful garnet coloured	327	sw 393
W CMa	6.6	2.4	363	31 Jan. 1785	deep garnet coloured	440	
R Lep	7.8	5.8	365	4 Feb. 1785	bright garnet	450	Hind‘s Crimson Star
19 Psc	5.0	2.6	461	8 Oct. 1785	deep orange red or pale garnet	-	TX Psc
RY Mon	7.5	4.4	529	24 Feb. 1786	deep garnet colour	637	
U Hya	4.8	2.7	541	19 Mar. 1786	deep garnet colour	-	sw 997
W Hya	7.7	1.3	550	28 Mar. 1786	deep garnet colour	657	
S Cep	7.4	4.7	762	10 Oct. 1787	deepest a. most brilliant garnet colour	787	
Y CVn	4.9	2.5	833	27 Apr. 1788	deep red	817	Secchi’s La Superba
RY Dra	6.3	3.1	954	20 Mar. 1790	deep garnet colour	939	
V466 Per	8.1	4.0	989	28 Dec. 1790	very deep garnet colour	976	
6 Gem	6.3	2.6	-	17 Feb. 1792	deep garnet	-	BU Gem; 7-ft
V419 Cep	6.6	2.3	1060	14 Oct. 1794	very deep garnet colour	1040	

Table 2-11: Herschel’s ‘garnet stars’ found in the period of the sweep campaign (see Table 1-15 for his earlier finds in the star reviews). All stars are variable. B-V = colour index; U = ‘unknown star’.

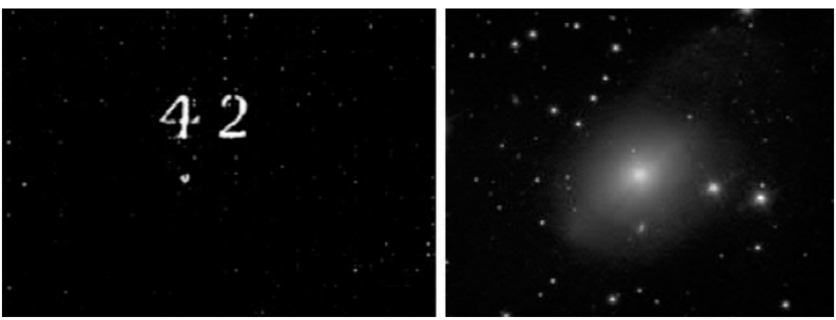
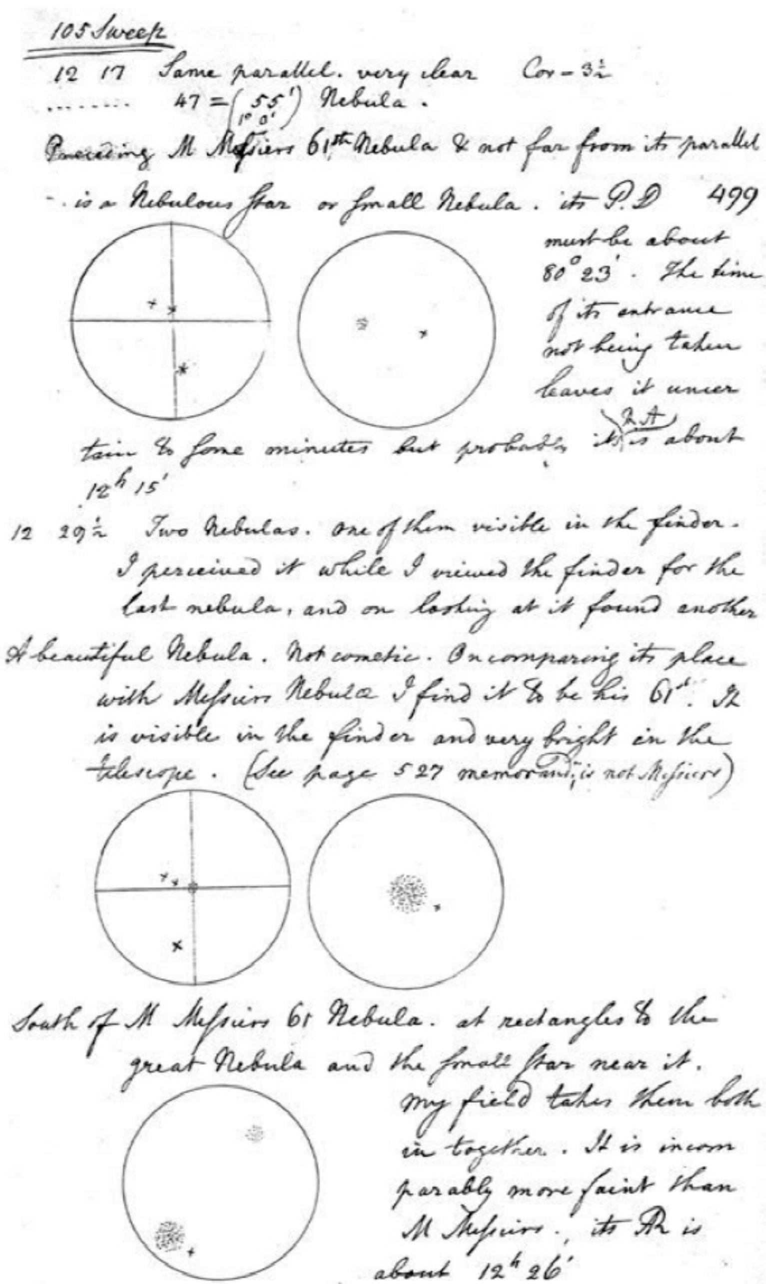


Figure 2-28: The galaxy NGC 2508 in Canis Minor, seen as a ‘doubtful nebulous star’; the sketch only shows a stellar object.

After sweep 99, Herschel revisited the cometary nebula NGC 2261

and the neighbouring cluster NGC 2251 in Monoceros, both discovered in sweep 67. Now he detected a double star, 33' northeast of NGC 2261; it was later catalogued as III 114. In sweep 100, an interesting galaxy was found in Canis Minor: NGC 2508 (III 7), seen as a “nebulous star, but doubtful as nebulosity” (Figure 2-28). Though sweep 104, when Herschel found the “longish nebula” NGC 4235 (II 17) in Virgo at ST 12^h 05.25^m, the night of 23 January went smoothly. This would change with sweep 105.



105 Sweep

12 17 Same parallel. very clear Cor – 3½

.... 47 = (55′ / 1° 0′) Nebula.

Preceding M Messiers 61th Nebula & not far from its parallel .. is a Nebulous star or small Nebula. its P.D 499 must be about 80° 23′. The time of its entrance not being taken leaves it uncertain to some minutes but probably its RA is about 12h 15′

12 29½ Two Nebulas. One of them visible in the finder. I perceived it while I viewed the finder for the last nebula, and on looking at it found another

A beautiful Nebula. Not cometic. On comparing its place with Messiers Nebula I find it to be his 61st. It is visible in the finder and very bright in the telescope. (See page 527 memorand; is not Messiers)

South of M Messiers 61 Nebula. at rectangles to the great Nebula and the small star near it. My field takes them both in together. It is incomparably more faint than M Messiers, its RA is about 12h 26′

Figure 2-29: The record of sweep 105 on 23 January 1784 as documented in *Fixt Stars No. 6* (see text)

A complex problem arose that created a host of other difficulties. The case involves six sweeps (105–110) and an astonishing number of catalogue entries: 2 M-numbers, 13 H-numbers, 6 h-numbers, 17 GC-numbers and 11 NGC-numbers. One must divide primary entries, due to observations by Messier, William and John Herschel (*Slough Catalogue*), from secondary ones, based on deskwork only (John Herschel's *General Catalogue*, Dreyer's *New General Catalogue*), which have a lower rank.[389] Due to the amount of data, only a brief account of the problem – and its solution – can be given here. The key object is the 'bright nebula' I 7, discovered in sweep 105, and later assigned the 'General number' (GN) 45.

The crucial sweep 105 started at ST $12^h\ 17^m$ (Figure 1-28) in Virgo.[390] The first event reads: "Preceding Messiers 61st nebula & not far from its parallel is a nebulous star or small nebula. Its PD must be about 80° 23'. The time of its entrance not being taken leaves it uncertain to some minutes but probably its AR is about 12^h 15^m [1690]." The nebulous star preceding M 61 was catalogued as II 18 (GN 44). There is only a PD index reading. In the revised records, Caroline gives for I 7 the position $12^h\ 19^m\ 06^s$, PD 80° 59' (1800). For II 18 the PD is the same, but for AR only a range is given: $12^h\ 19^m$ to $12^h\ 31^m$; not very helpful for an identification. Then, at ST $12^h\ 29½^m$, Herschel saw "Two nebulas, one of them visible in the finder. I perceived it while I viewed for the last nebula, and on looking at it found another." The first object was catalogued as 'bright nebula' I 7 (GN 45), the other as II 19 (GN 46). The former was sketched: "A beautiful Nebula. Not cometic. On comparing its place with Messiers Nebula I find it to be his 61st. It precedes 31 Bootis $2^h\ 0¾^m$ or follows 49 Leonis $2^h\ 6^m\ 45^s$." The distance to the reference stars is astonishingly large (about 30°); 49 Leo was measured in sweep 103 and 31 Boo in sweep 111 (the last of the night). The large difference in right ascension can cause significant errors in the position of unknown objects.[391]

Another nebula was found at ST $12^h\ 31½^m$: "South of Messiers 61 nebula, at rectangle [right angle] to the great nebula and the small star near it, my field takes them both in together. It is incomparably more faint than Messiers, its AR is about $12^h\ 26^m$ [1690]." The object was catalogued as II 20 (GN 47). The positions of the four nebulae are very uncertain; either there was no ST value or no PD

index reading.

On 23 February, Herschel noted about the problems: "It seems the sweeps 102 to 111 were not so well ascertained in situation as I could wish however it is evident that the beautiful nebula of the 105 sweep [I 7] is not Messiers 61st as was hastily surmised. The nebula of the 105 sweep & that of the same sweep are not near Messiers 61st but near that large new one which I had mistaken for his 61st." In *Journal No. 7*, to the right of the telescopic view Herschel noted: "Messiers 61 49 I believe" – an interesting correction.392 Indeed, M 61 is about 6° southwest of the (uncertain) place, determined for I 7.393 In a note to the first catalogue, he wrote:

I. 7. This remarkable appearance being no longer in the place it has been observed, we must look upon it as a very considerable telescopic comet. It was visible in the finder and resembled one of the bright nebulae of the Connoissance des Temps so much, that I took it for one of them [M 61] till I came to settle its place; but this not being done till a month or two after the observation, the opportunity of pursuing and investigating its track was lost.

Obviously, Herschel tried to find I 7 later, but searched in vain (there is no record about it). The obscure object was treated in a letter to Bode, dated 27 October 1801:394

On looking over the sweep in which the nebula I. 7 was seen, I find that there is a considerable uncertainty in the polar distance of five successive sweeps, owing to a change in the altitude of the telescope and want of well ascertained stars. […] My apparatus in 1784 was not so complete as it is now, and to solve the doubt about the place it will be necessary to sweep the zone in which the nebula or rather comet was taken over again. […] The comet, by the field of the telescope which is 15 minutes, must have been about 4 or 5 minutes in diameter. It had no nucleus, and there was a small star which could not be seen in the finder very near and a little north preceding it.

Herschel included sketches of the finder and telescopic views (Figure 2-30). The latter shows a faint star following the nebula about 1' (4^s). However, he made a mistake with the orientation.

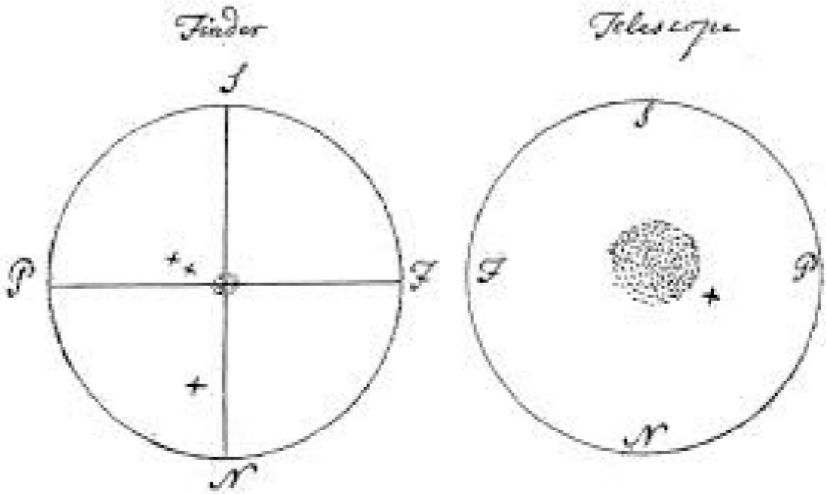


Figure 2-30: Herschel's sketches of the 'bright nebula' I 7 (finder and telescopic view), sent in a letter to Bode in 1801.

John Herschel, using Caroline's *Zone Catalogue*, tried to observe the objects found by his father on 23 January 1784. Interestingly, he was already warned by his aunt from Hanover, to treat the case with care:395

I have sent you a transcript of all sweeps which are connected with the 49th Leonis, made Jan. 23, 1784, and also all the nebulae observed in those sweeps: and such as have been seen again I have brought their additional observations all to one point for Jan 0, 1800 and wrote them with pencil under each observation for you to compare, which I can rub out when you have done with them (but NB. I have not the originals).

John checked the area in Virgo on 27 December 1827 (sweep 117). He could not find the bright nebula I 7, but saw three others, catalogued as h 1293, h 1384 and h 1474. Nevertheless, for the sake of completeness, I 7 was entered as GC 3146 in the *General Catalogue* with the description "very bright, very large (no doubt a comet)". Due to this information, Dreyer omitted I 7 in the NGC.

William observed the region again on 28 December 1785 (sweep 498). Three entries in *Sweeps No. 1* refer to nebulae in a 11' long chain, oriented south to north (in the current sweep direction). The

descriptions are “faint very [sic]”, “faint, pretty large” and “very bright, considerably large, gradually much brighter in the middle, extended with faint branches, is No. 49 of the Conois.”, respectively. The second was catalogued as II 498 (GN 1247). In *Sweep records No. 1*, the first was identified with II 18 (GN 44). Obviously, Caroline had used the lowest AR of the range. This identification, however, would imply that the AR of the objects I 7, II 19 and II 20, seen near to II 18 in 1784, is about 11.3^m (3°) lower than given in sweep 105. Bringing the unidentified ‘bright nebula’ I 7 about 3° to the west, we land at M 49! It is astonishing that no such conclusion was made by the Herschels.

By the data it is clear that I 7 is M 49. This implies identifications for II 18, II 19 and the nebulae seen in sweep 489: II 18 = NGC 4467 and II 19 = h 1293 = NGC 4470;[396] the latter is identical to II 498 (GN 1247) of sweep 498. The object identified as ‘II 18 (GN 44)’ in that sweep is actually NGC 4466 (Figure 2-31).

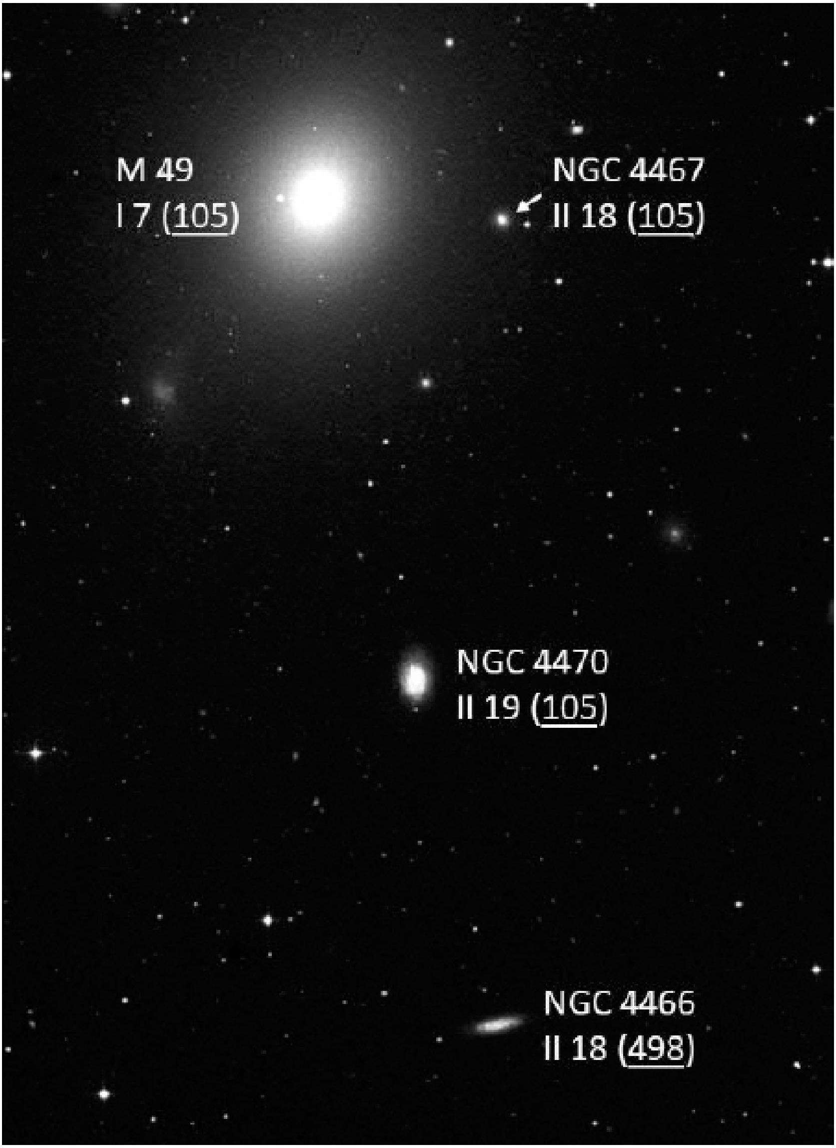


Figure 2-31: Herschel discovered M 49 and three galaxies in the vicinity (identified by their class designations), though in different sweeps (underlined number).

Thus, we have a large AR shift of 11.5^m which is 2.8° on the sphere (Figure 2-32). An explanation is a failure of the sidereal clock, happening in the ½ hour break between sweeps 104 and 105. The

only object found in sweep 104, the galaxy NGC 4235 (43 = II 17), still shows a correct position. A problem is the “considerable nebula” II 20, the fourth of sweep 105. The ST is essential to solve it. The object was seen two minutes after M 49 (by the clock) and 26' more south. However, there is no non-stellar object at the nominal place, about 22' southwest of M 49. Fortunately, we have a sketch in *Journal No. 7*. It shows a unique chain of six stars pointing to the nebula (Figure 2-33). Inspecting the region east of M 49, we find a perfect match: the 11.5 mag galaxy NGC 4612. Though the PD fits well, the position is 11.3^m east of M 49. Note that the difference equals the AR shift, which means that the failure is gone! However, this does not mean that Caroline’s position for II 20 is correct; it is about 2^m east of the galaxy. In sweep 191 (13 April 1784), Herschel found a nebula, designated II 148 (GN 320), also fitting well to NGC 4612, so we have II 20 = II 148. Curiously, this was noticed by Caroline, but NGC 4612 is not in the *Zone Catalogue*! The galaxy was later seen by John (h 1383), so we finally get: II 20 (47) = II 148 (320) = h 1383 = NGC 4612.

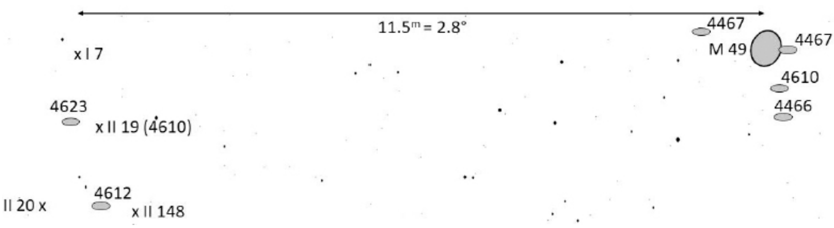


Figure 2-32: Map of the sky region east of M 49, showing the wrong positions (x) of the Herschel objects, mentioned in the text; only the relevant NGC galaxies are plotted.

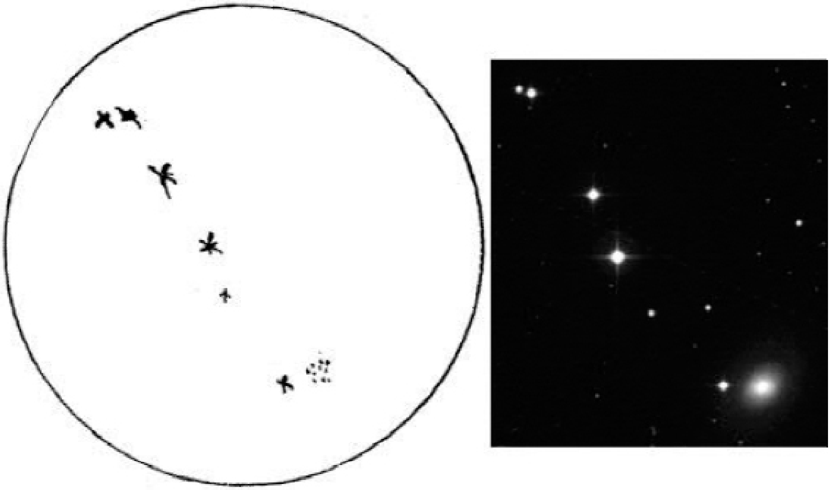


Figure 2-33: A nice star chain points the nebula II 20 (NGC 4612) in Virgo.

Back to Dreyer. Due to the wrong position of II 19, he was unable to see a relation with his nebula NGC 4470 near M 49. Thus, he created a new entry: NGC 4610, located 12^m east of it. Annoyed by the strange case, the Armagh Observatory Director wanted a solution for the *Scientific Papers*, which would include revised versions of the three Herschel catalogues. He wrote about I 7:[397] "In the sweep (105) this nebula is exactly 2^m preceding a nebula which is undoubtedly II. 20 = II. 148. The R.A. must therefore have been 12^h 32.5^m (for 1860). The fine nebula M. 49 is exactly 10^m preceding, and this nebula has a * 12 mag. 4^s following on the parallel, so that it seems fairly certain that I. 7 = M. 49." Dreyer refers to the sketch in Herschel's letter to Bode, known to him from the RAS archive (Figure 2-30). Although Dreyer was not aware of the true difference, he got the right result anyway.

The night of 23 January does not end here. It brought seven more objects (GN 48–54) in sweeps 106–110: I 8, II 21, II 22, III 9, III 10, III 11 and III 12. When inspecting their nominal positions, further problems arise. I 8 (GN 48) is described as a "considerable nebula"; the place is 1' east of the 10.6 mag NGC 4698 – a good match (the object is not in the *Zone Catalogue*). However, in sweep 87 (18 January 1784), William had found "a nebula" at the AR of that

galaxy, catalogued as III 6 (GN 38). Due to a problem with the PD index, Caroline could only estimate a PD between 78° 22' and 80° 29'. She later concluded that GN 48 is identical to that with GN 38, which is reasonable since there is no other nebula nearby. Due to the identification with the 'bright nebula' I 8; she described the object in the revised record of sweep 87 as "a nebula of the first class".

II 21 (GN 49) was found in sweep 107: "A nebula, very faint and of an irregular shape. About ½° south preceding the following star." Because there were no time and PD data, Caroline could only note an approximate position: "AR about 12^h 34^m -- PD 80° 55' ::". There is a suitable candidate for II 21, the 12.1 mag galaxy NGC 4795. There was no PD for II 22 (50) either: "A nebula so small that I lost it again while I looked into the finder." It should lie between 80° 28' and 81° 54' at AR 13^h 11^m 24^s. The best choice is the 13.9 mag galaxy NGC 5106. Then, in sweep 108, William saw "two very feeble nebulae in the northern wing of Virgo": III 9/10. Though the calculated AR is 2^m east of the galaxy pair NGC 5208/09, the identification is clear; the 13th mag objects are 3.6' apart (Figure 2-34).

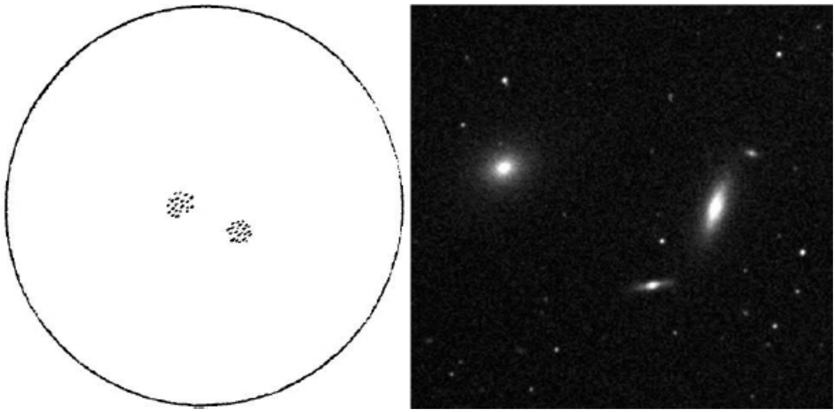


Figure 2-34: The galaxy pair NGC 5208/09 in Virgo, found on 23 January 1784.

The last discovery, III 12 (GN 54) in sweep 110, is described as: "A nebula. It is excessively obscure." Nothing is at the position in Boötes. However, six minutes later and 3' more south, Herschel saw

three stars: “The most south of 3 stars in a row, the largest and most north of which is my 38. II.” The double star II 38 was again observed in sweep 555 (19 March 1784); a reliable position was determined.398 Now, 6^m west and 3' north of the double star, we find the 13.7 mag galaxy NGC 5539, which must be Herschel’s obscure nebula. It is 56' northwest of the III 12 position. The problems in the curious night of 23 January continued until the very last objects! Table 2-12 shows all objects involved in the M 49 case (all are galaxies).

Sw	GN	H	NGC	Con	V	MD	ΔR (^{m})	ΔP (')	identical to	not identical to
100	40	III 7	2508	CMi	12.7		1.7	5	**h 484** = GC 1618	
101	41	III 8	2894	Leo	12.4		0.1	1	**h 603** = GC 1857	
102	42	II 16	3462	Leo	12.2		0.2	-1	**h 794** = GC 2258	
104	43	II 17	4235	Vir	11.6		0.0	2	**h 1159** = GC 2821	
105	44	II 18	4467	Vir	13.8	ST	0.0	12	GC 5654	**II 18** (**44**, sw 498) = NGC 4466
105	45	I 7	4472	Vir	8.4	PD	11.7	6	**M 49** = **h 1294** = GC 3021	GC 3146; **M 61** = **I 139** = **h 1202**
105	46	II 19	4470	Vir	12.1	PD	11.8	7	**h 1293** = GC 3020	NGC 4610 = GC 3147
105	47	II 20	4612	Vir	11.5		1.4	4	GC 3174; **II 148** (**320**, sw 191)	
106	48	I 8	4698	Vir	12.1		0.8	4	GC 3228; **III 6** (**38**, sw 87)	
107	49	II 21	4795	Vir	12.1	ST,PD	0.0	2	**h 1474** = GC 3302	
108	50	II 22	5106	Vir	13.9	PD	0.6	73	GC 3506	
108	51	III 9	5208	Vir	13.1		0.0	1	**h 1627** = GC 3582	
108	52	III 10	5209	Vir	13.0		-0.3	1	**h 1628** = GC 3583	
109	53	III 11	5417	Boo	13.0	ST	1.3	2	**h 1730** = GC 3746	
110	54	III 12	5539	Boo	13.7		2.8	37	**h 1767** (Nova) = GC 3828	NGC 5570 = **h 1781** = GC 3849

Table 2-12: Objects found on 23 January 1784; bold = observed object; MD = missing data

2.2.2. First quarter – a season for galaxies, sketches and new devices

The first quarter of 1784 was a very busy time for the siblings; 144 Sweeps were made. They yielded 209 discoveries in 23 nights; the best ones were 15 March with 44 new objects and 21 March with 35. The period of January to March was also a season for sketching. There are 58 figures in the sweep reports. In most cases the finder and telescopic views are presented. Rough sketches, first appearing in the *Journal*, were copied in a better quality in the *Fixt Stars* series.

Moreover, new methods were introduced and technical improvements made. The period is typical for Herschel’s observing, and looking at the reports, one can study all relevant features about recording, identification and cataloguing of non-stellar objects

(other types will be treated later) – including the problems. Another reason for looking at the first quarter is Herschel's important publication of 1784 on the 'construction of the heavens'. The sweeps brought enough data to summarize the results and draw conclusions – no time was wasted. The draft, written by Caroline, was finished in April and timely sent to the *Royal Society*. The paper also contains a table of 15 sketches, rendered for printing. The content of Herschel's important publication is reviewed in section 4.1.1.

24 January, starting with sweep 112, brought the first use of a new device, called 'PD string'. In 1786, William told some details.[399] The text describes how the actual tube elevation was transmitted to Caroline's desk in the nearby house (Figure 2-24).

I found also that, by the turns of the handle which gave motion to the telescope, it was practicable, in a coarse way, to ascertain the difference of altitude between any two objects that passed the field of view; on which account, Dec. 30, I began to use an index board, divided into inches, and marked with numbers, which, being placed behind the rope that moved the telescope, would point out at what altitude a certain index, affixed to the rope, was situated. My tackle of ropes and pullies was such that, while the telescope traversed an arch of two degrees, the mark on the rope passed over 24 inches of the index board: but the exact measure was always to be determined experimentally, as it varied according to the situation of the instrument. I perceived immediately that the quantity of rope used in the motion of the telescope would be much better within doors near the writing desk: to effect this, I used a small cord, which, being led off from the great one, was carried over a pulley into the observatory, so as to pass over a set of numbers, which I now divided into such parts as, in an equatorial situation of the instrument, would give nearly to one minute.

The vertical motion of the telescope was controlled by a handle, turned by a workman at the tube base. The rotation corresponding to the PD index was transmitted horizontally to Caroline's desk in the nearby house by means of a pulley and belt (or chain). Now she could read the index value by a pointer mechanism.[400] Caroline wrote down both the sidereal time and the object altitude. With

sweep 126 on the 25th the index scale was reversed: highest number = largest PD (lowest tube elevation), lowest number = smallest PD (highest tube elevation).

The night brought a total of 14 sweeps, performed in 12 hours (112–125). Seven galaxies were discovered in Virgo and Sextans. In sweep 116, Herschel saw a “nebula or cluster of very close and faint stars”, catalogued as VI 4. However, the place in Sextans is occupied by the 12.1 mag galaxy NGC 3055. This is one of two cases where he chose a class VI designation – usually applied to globular clusters – for a nebula.[401]

In sweep 123, Herschel observed only one object: “A very large, but excessively faint nebula, or, I believe there are very close and very small stars.” His sketch shows a round nebula of about 5' diameter, much looking like a resolved globular cluster (Figure 2-35). The finder and telescope views show existing stars – the position is correct. Obviously, the large distance to the reference star (75 Leo, 26° east) had no influence. However, nothing is at the place and no comet roamed the region. Herschel catalogued the obscure object as ‘large nebula’ V 3 and Dreyer lists it as NGC 4910 (see Table 2-16). In the last sweep of the night (125), a second double star was found, located in Virgo. Caroline later introduced a new designation (N), now counting the objects found in the sweeps or later observations. The Virgo pair opened her list as N1 (it ends with N145).

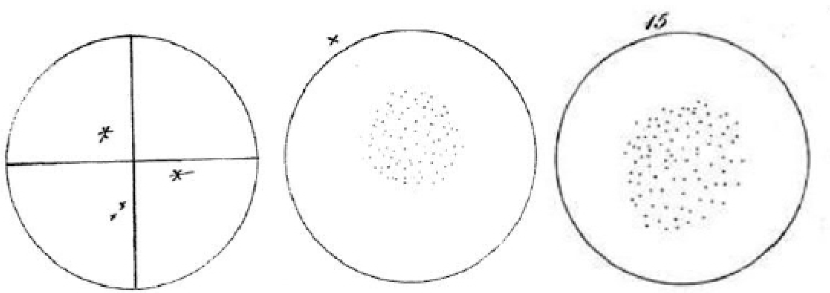


Figure 2-35: Finder and telescopic view of the non-existent ‘large nebula’ V 3 (NGC 4910) in Virgo, which Herschel believed he saw on 24 January 1784 in sweep 123; right: rendered version of his sketch, published in 1784.

Sweep 134 on 30 January brought another innovation: Alexander had constructed a ‘bell mechanism’ (Figure 2-36). The breadth of a sweep (PD range) was now controlled by two bells, ringing when the desired upper/lower limit was reached. Prior to the sweep, the distance between them was set (a note like ’10 Bells’ refers to it). The mechanism could be adjusted according to the number of turns of the sweeping handle required to raise the telescope by about 2°. When a bell rang, the workman changed the motion direction.[402] The new tool is described on 8 February (below the record for sweep 136):

By way of determining the breadth of my sweeps with greater accuracy I have added a small machine, which strikes a bell at each extreme of the intended breadth of the sweep by which means the person at the motion is guided much better than by counting the turns or seeing the motion of a mark on the rope which requires light & greater attention. I can set the bells at any distance so as to strike at any given number of turns of the handle. The number of bells are by a table known in numbers on the board which gives the declination.

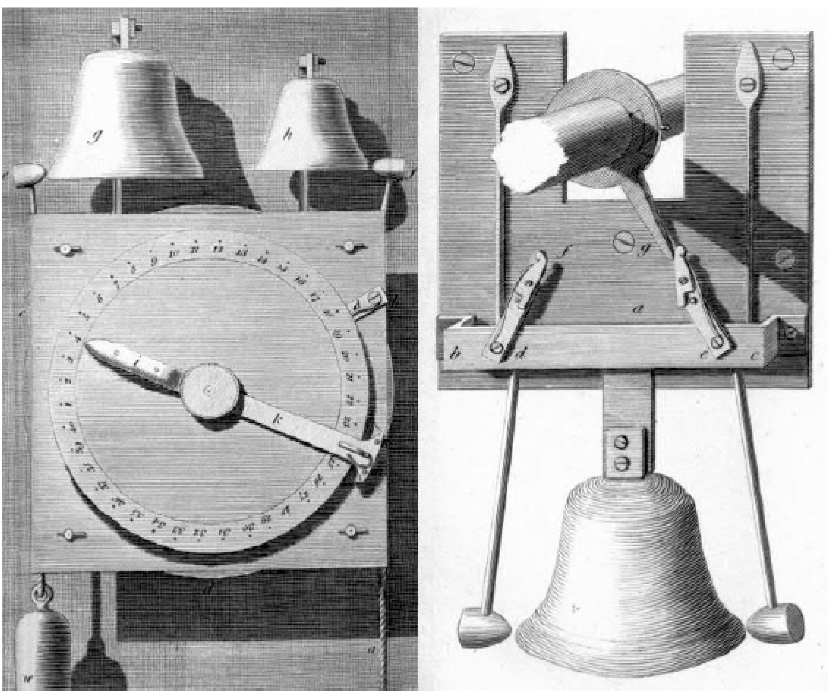


Figure 2-36: Alexander's bell mechanism; here the later version, installed at the 40-ft telescope.[403]

Although the January observations could not start until the 17th, the month nevertheless brought 40 discoveries in only seven nights! The new sweeping method was enormously productive – and the Herschels were full of energy. However, the positions were still not good enough for a clear identification. Later, 10 of the 40 objects were seen again and catalogued as new. A remarkable example of the many identities among Herschel's objects is the galaxy NGC 4119 in Virgo, occupying three different entries: II 14, I 33 and II 60 (see Table 2-17).

The PD could now be determined more precisely (Table 2-13), but AR still caused problems. No doubt the installation of a pendulum clock showing sidereal time, constructed by Alexander, was a major step. However, the moment of the meridian crossing had to be taken correctly. When the tube is perfectly aligned, the meridian is in the centre of the field of view. But how can you determine that without a marking? Herschel wrote on 14 March 1784 (following sweep 170): "I have no cross wire in the telescope [eye-piece] for taking passages as I could not introduce them without obstructing the field in the best part; I submit therefore rather to the inaccuracy arising from the want of them than run the risk of not seeing very minute & delicate objects well." For brighter stars, Herschel followed their transit in the finder, equipped with a crosshair, but this was not a good solution.[404] If clouds came up and no Flamsteed star had passed the telescope field of view yet, Herschel was forced to 'measure' a star by the finder. This happened in sweep 234 (10 July 1784)"; ¾ deg under 2' past Lyra by the finder. These kinds of coarse observations are made when no known star of Fl. has been had before, lest some sudden clouds would terminate the sweep without allowing the proper time for determining its situation."

Innovation	Date	Sweep	Remarks
PD index	30 Dec. 1783	68	100 numbers, highest = top
PD string	24 Jan. 1784	112	elevation transfered to the desk
reversed PD scale	25 Jan. 1784	126	highest number = bottom
bell mechanism	30 Jan. 1784	134	adjustable top/bottom bells
quadrant	24 Jun. 1784	232	direct measure of the altitude
new PD scale	11 Oct. 1784	288	150 numbers (highest = bottom)
PD clock	24 Sep. 1785	440	direct PD reading

Table 2-13: Technical innovations in measuring the PD (see text).

On 11 February (sweep 138), an interesting open cluster in Orion was found, NGC 2194 (VI 5): "A cluster of very close stars, rich and of a large extent, i.e. about 7 or 8' or more." The object was sketched (Figure 2-37 Figure 2-37).[405] Clouds terminated the sweep after 2.5 hours.

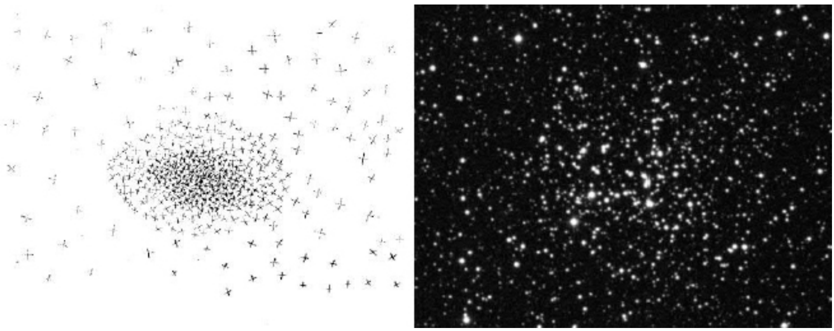


Figure 2-37: The open cluster NGC 2194 in Orion, sketched on 11 February 1784. Note the oval shape.

During the day, Herschel still found time to cast new mirrors. In sweep 143 (15 February) he used "A new large object speculum. It is very bright but not quite so distinct as my first; I shall however use it all the night."[406] An interesting open cluster in Taurus was discovered, NGC 1647 (VIII 8). It is bright (6.4 mag), large and at a prominent place, right in front of the Hyades 'V'. Herschel noted: "A cluster of scattered stars consisting of chiefly large ones, it takes up above 20' of space; but there is not a great number of them." In sweep 146 (same night), he found five galaxies in Leo. Among them is the close pair NGC 3226/27 (II 28/29), located only 50' east of γ Leo. The companions are separated by only 2': "Two nebulae almost

close together." A sketch was made "by memory after the end of the sweep" (Figure 2-38). An hour later, another close pair was found 2° east of δ Leo and also sketched (Table 2-32): NGC 3646/3649 (III 15/16); the distance is 8'. Herschel noted: "A large nebula followed by a small one, in the same field of view with it." Obviously, the 'double nebula' seemed to be a frequent phenomenon.

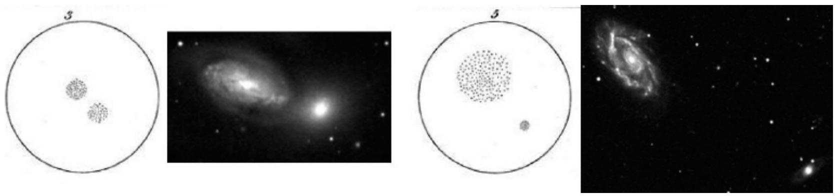


Figure 2-38: Two double nebulae, found on 15 February 1784 in Leo. Left: NGC 3226/27; right: NGC 3646/49 (the modern images are not to scale).

The sweep also brought Herschel's first globular cluster discovered in a sweep: NGC 4153 in Coma Berenices (following NGC 6535 in Serpens, found in 1780). He noted: "A bright nebula, not very large, however of some extent; it is not round, the greatest brightness lies towards the middle but is not circular. The whitishness of this nebula is of the milky kind of those unresolvable nebulae such as Orion etc." Obviously, the 10.4 mag object was too compact to show single stars; consequently, it was catalogued as 'bright nebula' I 11 (Figure 2-39).

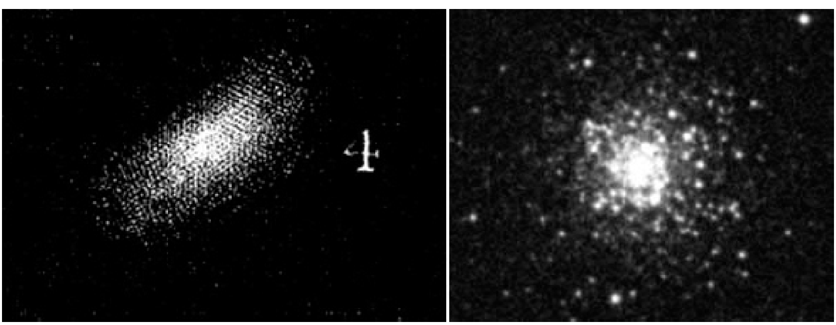


Figure 2-39: The globular cluster NGC 4153 in Coma Berenices, sketched on 15 February 1784. Herschel could not resolve the small compact object, seen as 'not round'.

Of the finds on 22 February, five are interesting, and thus sketched by Herschel (Figure 2-40). In sweep 153, he discovered the 9.0 mag galaxy NGC 3521 (I 13) in Leo: “A fine bright nebula, with a bright star or nucleus in the middle; it sends out a milky ray towards the north, and another more faint towards the south; the extend of the whole, faint rays included, may be about 7 or 8'.” It was followed by NGC 3662 (IV 4) in Leo: “An exceedingly faint nebula, consisting of a nucleus with a small very faint brush south preceding. The brush is not regularly fan shaped.” The galaxy has 12.9 mag; the “nucleus” is a superimposed 14 mag star (Table 2-26, Figure 2-92). In sweep 154, Herschel encountered an extremely elongated object, the 10.4 mag edge-on galaxy NGC 4517 (IV 5) in Virgo, having an axis ratio of 7.[407] He noted: “A pretty bright star, with a milky ray on the south side of it, extending from east to west or rather from north preceding to south following. It does not seem to touch the star, and is about 10 or 12' in length.” The star has 11 mag. In the same sweep, he found the 11.6 mag galaxy NGC 4592 (II 31) in Virgo. We read: “A nebula, extended from east to west and also towards the north; it is not cometic and seems to be resolvable.” The object has a slightly triangular shape. Finally, we have NGC 4666 (I 15), a 10.7 mag bright edge-on galaxy in Virgo: “A nebula, elongated from sp to nf, seems to contain bright places to be resolvable. It resembles the foregoing nebula [NGC 4632] but is narrower.”[408]

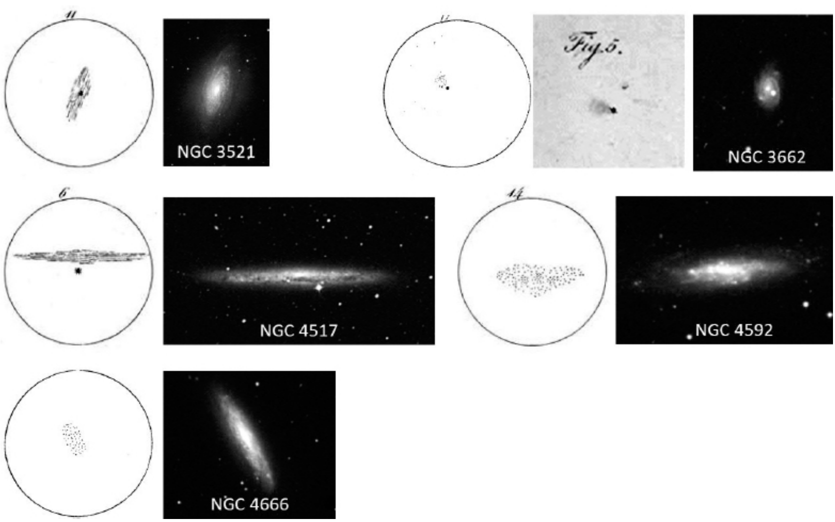


Figure 2-40: Five interesting nebulae, found on 22 February 1784 in sweeps 153 and 154, made in Leo and Virgo.

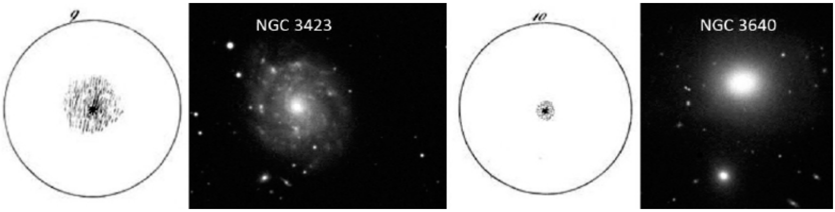


Figure 2-41: Two objects, found on 23 February 1784. Left: The face-on 11.1 mag galaxy NGC 3423 in Sextans, showing a stellar centre. Right: The 10.4 mag galaxy NGC 3640 in Leo.

On 23 February, two nebulae were found and sketched (Figure 2-41). Since the first is involved in a curious story, we start with the second, found in sweep 158. Herschel saw “A very large nebula; cometic with a bright point in the centre, the nebulous part is extremely faint.” This is the 10.4 mag galaxy NGC 3640 (II 33) in Leo.

This cannot be said about the first nebula of sweep 157. The case shows, how difficult it was for the siblings to manage the amount of data. In Sextans, near the border to Leo, William saw “A large faint nebula; cometic with a bright point in the center. The nebulous part is extremely faint.” The special appearance of the object led to the designation IV 6. The position clearly points to an 11.1 mag galaxy, verified by John (h 777) and catalogued as NGC 3423 by Dreyer. The spiral is seen face-on with a stellar nucleus. On 13 April (sweep 191), Herschel encountered an object, located 28' east of NGC 3423: “I suspected a nebula but did not verify it, as I would lose no time in this place.” It was designated III 88. Although John searched in vain, Dreyer catalogued the nebula as NGC 3401. About two minutes later, William saw “A very large pretty bright resolvable nebula; almost round, and but a little brighter middle.” Because the calculated position differed by -30^s in AR and -3' in PD from his nebula IV 6, Caroline could not see an identity; thus, it was catalogued as a new object, II 131. However, Dreyer was sure that IV 6 = II 131, so there is no new NGC-number in this case. Another four observations would follow, without clarifying the case. On 2 February 1786 (sweep 521, Herschel visited the region in eastern

Sextans again. Due to the description, he was sure to see his nebula IV 6 near its former place. This was confirmed on 17 April (sweep 553), but there is no reference to II 131 or III 88. Another observation was made on 30 December (sweep 675), using the 'front-view': "considerably faint, round, very gradually brighter middle, 4 to 5' diameter, almost condensed to a very large nucleus in the middle." Because the determined position fits to III 88 (NGC 3401), Herschel believed he had viewed his first object of sweep 191. This was confirmed in sweep 1098 on 12 April 1801, though the description differs: "Very bright, very large, irregular round, resolved." No doubt except the 'suspected nebula' of sweep 191, all other observations refer to the same galaxy. So we have: IV 6 = II 131 = NGC 3423 (galaxy); III 88 = NGC 3401 (not found).

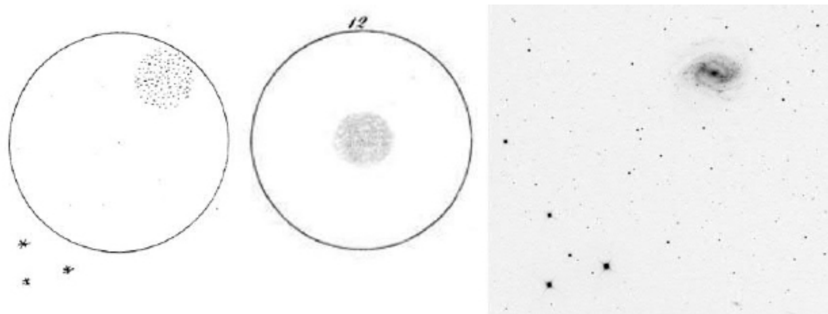


Figure 2-42: The face-on barred spiral galaxy NGC 4123 in Virgo, found on 25 February 1784; note the nice star trio nearby.

On 25 February (sweep 158), Herschel saw "a very faint nebula of a considerable extend, being about 5 or 6' diameter. To the north of the nebula at the distance of about 15' or more is a bright triangle of stars the base whereof is towards the nebula." This is the 11.4 mag galaxy NGC 4123 (V 4) in Virgo (Figure 2-42).

On 11 March (sweep 164), Herschel noted: "Three nebulae in the field together. The two preceding ones cometic & much like the two former bright ones [M 65 & 66] but considerably less. The following one is resolvable & of a longish form. These three together form a beautiful sight." The galaxies are all inside 10'; it was his first trio seen in a single field. The brightest member is M 105, already found by Méchain on 24 March 1781.[409] Since Herschel didn't know that, the 9.3 mag galaxy was catalogued as I

17. The other galaxies are NGC 3384 (I 18) and NGC 3389 (II 41), having 9.9 and 11.9 mag, respectively. A sketch was made in sweep 177 (19 March), when the M 105 trio was observed a second time (Figure 2-43). Three more observations exist: sweep 188 (12 April 1784), sweep 531 (24 February 1786) and sweep 555 (22 April 1786).

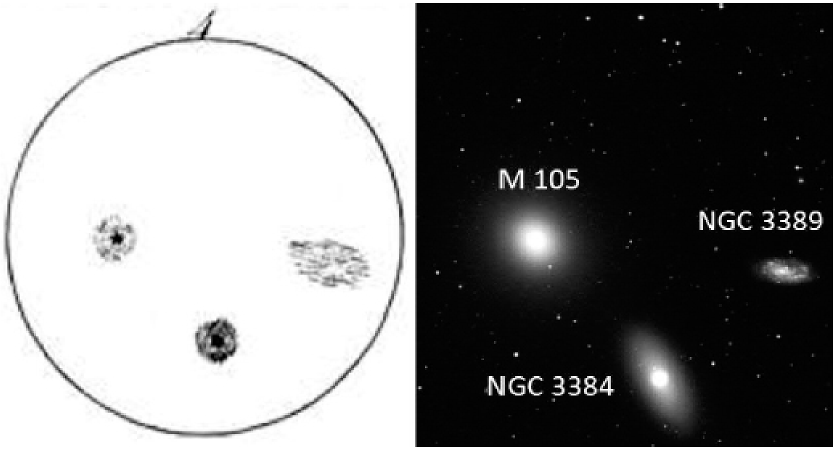


Figure 2-43: The galaxy trio M 105, NGC 3384 and NGC 3389 in Leo, found on 11 March 1784 in a single field of view.

In sweep 166 on 12 March, Herschel confirmed a suspected nebula with eye-piece No. 4 (240×); the object is the 13.8 mag galaxy NGC 3088 (III 24) in Leo, a high surface brightness object. When he continued sweeping, he forgot to shift to the standard eye-piece (157×), writing: "A very large star; but by mistake I found No. 4 continued instead of the sweeping power, so that some allowance must be made in the magnitude." Because the 5.7 mag star was not entered in the *British Catalogue*, but observed by Flamsteed, Caroline listed it as 'omitted star' O408.

On 14 March 1784 (sweep 170), the globular cluster M 53 in Coma Berenices was observed and sketched (Figure 2-44). Herschel was enthusiastic about the view: "It is one of the most beautiful objects I remember ever to have seen in the heavens; The cluster appears under the form of a solid ball consisting of small stars quite compressed into a blaze of light, with a great number of loose ones surrounding it and distinctly visible in the general mass." M 53 was

first seen on 27 February 1783 with the 7-ft reflector. In sweep 171 (same night), the last of 58 sketches, scattered in the *Journal* and *Fixt Stars* series was made. Herschel noted: “The figure only by memory soon after.” It shows NGC 6046 (III 33), a faint galaxy in Hercules: “A nebula suspected by 157 and the suspicion strengthened by 240; but latter power does not remove all doubt.” Actually, this is a rare ‘ring galaxy’ (of course, this feature was impossible to see).

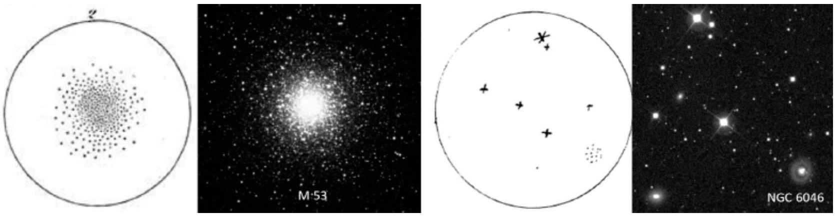


Figure 2-44: Two objects, observed on 14 March 1784. Left: The globular cluster M 53 in Coma Berenices, “one of the most beautiful objects I remember ever to have seen in the heavens”. Right: The 13.5 mag ‘ring galaxy’ NGC 6046 in Hercules.

A sample of sketches was rendered in Herschel’s paper of 1784 on the ‘construction of the heavens’ (Figure 2-45).[410] The published table contains 15 figures (Table 2-14). All objects could be identified.

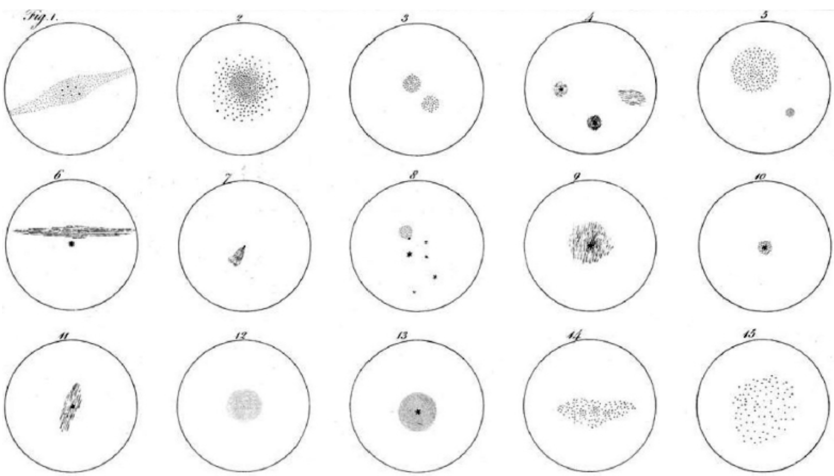


Figure 2-45: The sample of 15 Herschel sketches, published in 1784.

Fig.	NGC/M	H	Date	Sw	Con	V	Type	Remarks	Presentation
1	M 98	-	30 Dec. 1783	73	Com	10.1	Gx		Figure 2-23
2	M 53	-	14 Mar. 1784	170	Com	7.7	GC		Figure 2-44
3	3226	II 28	15 Feb. 1784	146	Leo	11.4	Gx	double system	Figure 2-38
3	3227	II 29	15 Feb. 1784	146	Leo	10.3	Gx	double system	Figure 2-38
4	M 105	I 17	11 Mar. 1784	164	Leo	9.3	Gx		Figure 2-43
4	3384	I 18	11 Mar. 1784	164	Leo	9.9	Gx		Figure 2-43
4	3389	II 41	11 Mar. 1784	164	Leo	11.9	Gx		Figure 2-43
5	3646	III 15	15 Feb. 1784	146	Leo	11.1	Gx	double system	Figure 2-38
5	3649	III 16	15 Feb. 1784	146	Leo	13.7	Gx	double system	Figure 2-38
6	4517	IV 5	22 Feb. 1784	154	Vir	10.4	Gx		Figure 2-40
7	2261	IV 2	26 Dec. 1783	67	Mon	9.0	RN	Hubble's Variable Nebula	Figure 2-19
8	2245	IV 3	18 Jan. 1784	81	Mon	11.0	RN		Figure 2-26
9	3423	IV 6	23 Feb. 1784	157	Sex	11.1	Gx		Figure 2-41
10	3640	II 33	23 Feb. 1784	158	Leo	10.4	Gx		Figure 2-41
11	3521	I 13	22 Feb. 1784	153	Leo	9.0	Gx		Figure 2-40
12	4123	V 4	23 Feb. 1784	158	Vir	11.4	Gx		Figure 2-42
13	2775	I 2	19 Dec. 1783	57	Cnc	10.1	Gx		Figure 2-18
14	4592	II 31	22 Feb. 1784	154	Vir	11.6	Gx		Figure 2-40
15	4910	V 3	24 Jan. 1784	123	Vir	-	NF		Figure 2-35

Table 2-14: The 15 sketches, presented in Table XVII of the 1784 paper on the 'construction of the heavens'. All are shown in the text ('Presentation') and compared to modern images.

The first quarter of 1784 was a time of galaxies. Herschel mainly observed in Virgo, Coma Berenices and Leo, now known as a playground for extragalactic objects. In these constellations, he found 55, 50 and 26 galaxies, respectively. Of course, some double or triple systems are among them: we have 15 pairs and 4 trios (Table 2-15). The trio NGC 4564, NGC 4567 and NGC 4568 in northern Virgo (catalogued as II 68, IV 8 and IV 9) is interesting; the last two form an overlapping pair (distance 1.2'), known as the Siamese Twins. Herschel wrote: "A double nebula, or two pretty considerable nebulae apparently run into one another. The foregoing nebula [NGC 4564, 11' north] may be taken into the field of view with these two."[411]

Sw	1784	Con	NGC	H	GN	V	Dist (')	Remarks
105	23 Jan.	Vir	4472	I 7	45	8.4		M 49; Figure 2-30
			4610	II 19	46	12.1	11	
108	23 Jan.	Vir	5208	III 9	51	13.1		Figure 2-34
			5209	III 10	52	13.0	4	
146	15 Feb.	Leo	3226	II 28	74	11.4		Figure 2-38
			3227	II 29	75	10.3	2	
146	15 Feb.	Leo	3646	III 15	77	11.1		Figure 2-38
			3649	III 16	78	13.7	7	
158	23 Feb.	Vir	4496	II 36	98	11.4		close pair; Figure 2-101
			4505	III 18	99	13.9	1	close pair
164	11 Mar.	Leo	3379	I 17	106	9.3		M 105; Figure 2-43
			3384	I 18	107	9.9	7	
			3389	II 41	108	11.9	6	
166	12 Mar.	Leo	3190	II 44	117	11.2		
			3193	II 45	118	10.9	11	
170	14 Mar.	Leo	3605	III 27	125	12.3		
			3607	II 50	126	9.9	3	
			3608	II 51	127	10.8	6	
172	15 Mar.	Leo	2872	II 57	143	11.9		close pair
			2874	II 58	144	12.5	1	close pair
174	15 Mar.	Vir	3848	III 35	149	13.1		
			3852	III 36	150	13.0	4	
174	15 Mar.	Vir	4294	II 61	153	12.1		
			4299	II 62	154	12.5	6	
174	15 Mar.	Vir	4491	III 41	163	12.6		
			4497	III 42	164	12.5	12	
174	15 Mar.	Vir	4564	II 68	167	11.1		
			4567	IV 8	168	11.3	11	Siamese Twins
			4568	IV 9	169	10.8	1	Siamese Twins
174	15 Mar.	Vir	4638	II 70	173	11.2		II 176; not in *Zone Catalogue*
			4647	III 44	174	11.3	15	
			4649			8.8	2	M 60
174	15 Mar.	Vir	4754	II 74	178	10.6		
			4762	II 75	180	10.3	11	edge-on
177	19 Mar.	Leo	3020	III 51	190	11.9		
			3024	III 52	191	13.1	6	edge-on
181	21 Mar.	CNC	2802	III 62	206	14.3		close pair; Figure 2-101
			2803	III 63	207	14.0	1	close pair
182	21 Mar.	Com	4340	II 85	218	11.2		
			4350	II 86	219	11.0	6	
182	21 Mar.	Com	4489	II 91	224	12.0		
			4498	II 92	225	12.1	13	
			4502	III 69	226	13.9	11	

Table 2-15: Double and triple galaxies found in the first quarter of 1784.

Another interesting case is the close pair NGC 4496/4505 (II 36/III 18) in Virgo. The galaxies are only 52" apart (see Figure 2-101 and Table 2-28). According to Herschel's record, they were found in subsequent fields; the time difference is given as 1 minute. If they had been in the centre when the tube moved vertically, they were seen together, of course. But Herschel must have encountered NGC 4496 at the eastern side of the field. He stopped the sweep motion and while describing the object ("a faintish pretty large nebula, it seems to be resolvable"), it moved towards the centre, where the time was taken. Meanwhile NGC 4505 must have entered the field: "Very faint, of a considerable size; it seems to be resolvable." After another minute, the sweeping motion was continued.

Ten Messier objects were observed from January to March; all are galaxies. Six of them were viewed for the first time: M 49, M 58, M 59, and M 60 in Virgo, M 85 and M 100 in Coma Berenices. Moreover, the additional Messier object M 105 in Leo (with its two companions) was found.

Two of the known ones had their premiere in the 18.7-inch: the globular cluster M 53 in Coma Berenices and the open cluster M 67 in Cancer. For the latter, Herschel noted: "A most beautiful cluster of stars, immensely rich." Once more, he was impressed by the power of his telescope. In contrast to many of the newly discovered nebulae, appearing like faint oval spots, Messier objects looked impressive in the large telescope.

Immediately after M 53 (observed in sweep 170 on 14 March) another globular cluster was discovered only 1° southeast: NGC 5053 (VI 7); Herschel noted: "An excessively faint cluster of stars intermixed with resolvable nebulosity 8 or 10' in diameter. The stars are so small that they cannot be seen without the greatest attention. 240 verified it beyond all doubts. I have suspected many such in this neighbourhood."[412] The exceptional pair of globular clusters is shown in Figure 2-46.

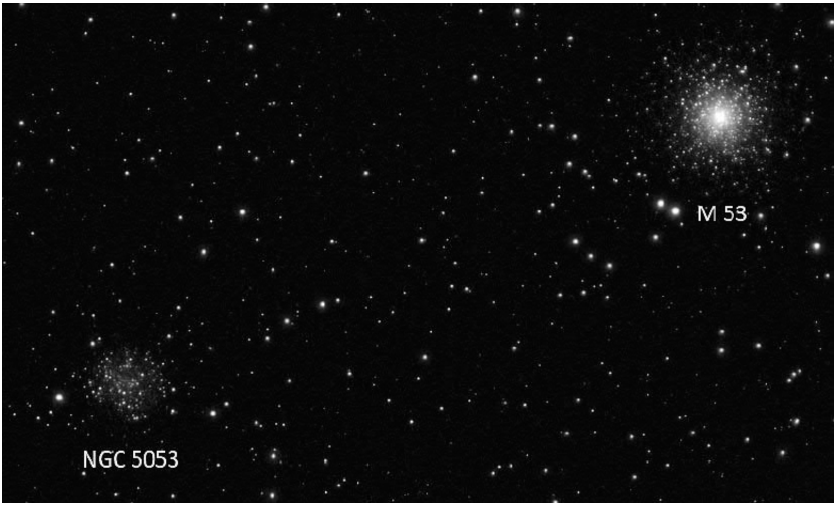


Figure 2-46: An exceptional pair of globular clusters in Coma Berenices: M 53 and NGC 5053, located only 1° southeast. Herschel discovered the faint, loose companion on 14 March 1784.

Obviously, the difference between the globular clusters M 53 and NGC 5053 in Coma Berenices is their star density. To quantify this feature, Harlow Shapley and Helen Sawyer introduced a 'concentration class' in 1927, ranging from I (highest density) to XII (lowest density).413 M 53 is in class V and NGC 5053 in class XI.

Sweep 168 on 14 March, made in Gemini, was interrupted for one hour: the "Duke of Gordon with some company saw some objects", probably not with the 20-ft.414 Though such illustrious guests enhanced Herschel's reputation, he was not always amused about events, interrupting the nightly work. After entertaining the visitors, sweep 169 was started. A mystery began, involving two objects in Cancer, II 48 and II 80, located only 2.2° southwest of Praesepe (Figure 2-47).415 Herschel wrote about II 48: "A nebula, resolved, pretty large, large brighter middle, than towards the extremes and contains one star following the brightness & very near to it." The reference star was 85 Gem. The other object, II 80, was found on 21 March (sweep 181): "Pretty bright, pretty large, elongated, resolvable. I can see 2 or 3 stars in it." The reference star was δ Cnc. This is the 11.6 mag double galaxy NGC 2672/73; because the companions are only 30" apart, Herschel did not perceive a pair.

Alas, there is nothing at the place of II 48, about 12' southwest of II 80. On 13 February 1787 (sweep 698), William noted: “I looked for II. 48, but could not find it. It was however not so well looked for as it ought to be, in order to ascertain its absence.” Caroline later added: “The nebula was perhaps looked for too late, for in recalculating, it was found to be 2' less following 85 Geminor. than what is given in the Cat. of the 1st 1000 nebula; and besides it is within the minute of the bottom of the sweep.” A further note reads: “By recalculation since the above, it is 8' below the sweep.” The position error, made in the first observation, is probably due to the reference star 85 Gem, lying 12.7° west of the object. With only 1.4° δ Cnc, is much closer. It took a long time, involving many astronomers, until it was clear that II 48 = II 80.416

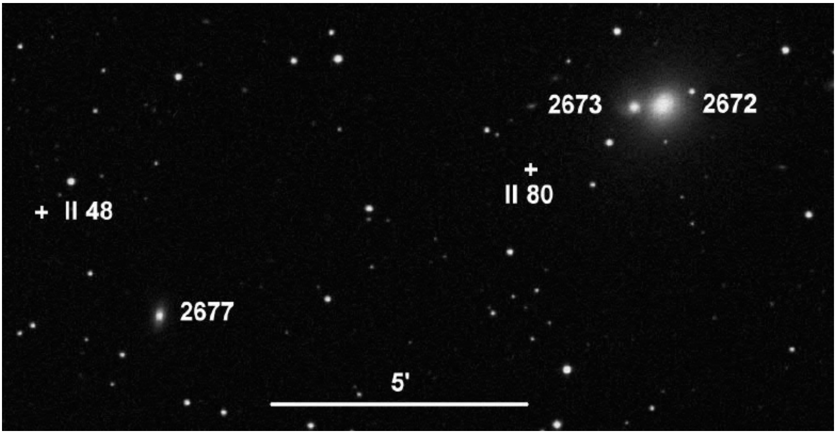


Figure 2-47: The strange case of II 48 and II 80 in Cancer and the galaxies NGC 2672/73 and NGC 2677 (see text).

On 15 March (sweep 174), Herschel experienced three cases, where a galaxy is accompanied by a bright star. This was not favourable concerning the dark adaptation and he always tried to get the star out of the field. The first case was NGC 3666 (I 20) in Leo: “An extended, resolvable nebula. A very bright star may be taken into the field of view with it.” The 5.8 mag star is 9.5' northeast. The next concerns NGC 4608 (II 69) and the 4.9 mag star ρ Vir (10.7' northeast): “A nebula, it may be taken into the field with 30 (ρ) Virginis.” Finally, we have the interesting case of NGC 5174, 11.8' north of 71 Vir (5.7 mag): “Two very faint. I took them first for only

one but 240 shewed two excessively faint nebulae as it were running into each other and of considerable extent; 157 shewed also a division between their centers after I had seen them with 240. They follow 71 Virginis within a minute." Actually, there is only one galaxy (NGC 5174 = III 45); the other object (NGC 5175 = III 46) is merely a 12.6 mag star, 2.3' northeast.

In sweep 205 (24 April) we have another example: NGC 4989 (II 185), 13.5' northeast of the 4.4 mag star θ Vir: "A small faint nebula; near a pretty bright star." The sweep also brought a bright galaxy in Virgo: NGC 4697 (I 39); the 9.6 mag object was sketched (Figure 2-48). Herschel wrote: "very bright, very large, irregularly extended, but the brightness breaks off abruptly so as almost to resemble a resolvable nucleus consisting of 4 or 5 bright stars, there is however too much moonlight to describe the nebula completely." The elongated elliptical galaxy was seen again in sweep 913 on 20 March 1789.

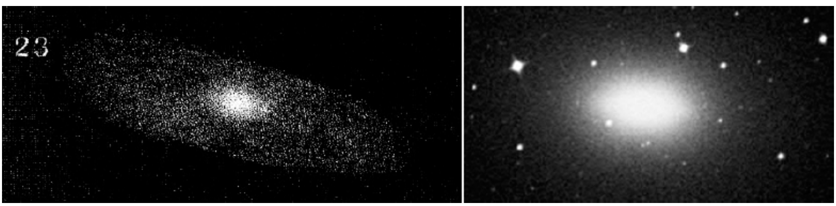


Figure 2-48: The 9.6 mag elliptical galaxy NGC 4697 in Virgo, sketched on 24 April 1784.

On 15 March (sweep 174), a unique case happened: a galaxy was found twice in a single sweep! Figure 2-49 shows the situation in Virgo. Because of the tube motion, continuously offering new things from the east (higher AR), this would imply a forbidden 'back motion'.[417] When Herschel discovered the 10.5 mag galaxy NGC 4754 (I 25) in Virgo, the tube moved upwards. He noted: "Bright, small, in a line with two stars", which fits exactly. 45 seconds later, he saw a pair: "Two pretty bright nebulae; The preceding of them is almost round, the following very much extended; they are not far from the same parallel and about 8 or 10' distant from each other." The objects were seen in a single field and catalogued as II 74/75. So far so good. But II 74 is NGC 4754! The galaxy has a 10.1 mag companion, NGC 4762, seen edge-on and located 11' southeast.

Thus, we get I 25 = II 74 = NGC 4754 and II 75 = NGC 4762 (see Table 2-15 and Table 2-17). How is this possible? The analysis of the sweep motion clears the case. When Herschel saw I 25 (NGC 4754), the companion was out of the field (to the east). While describing his find, it moved towards the centre. Then the tube was moved up a whole field and to turn back abruptly about the same distance. Now two nebulae entered the field: II 74 and II 75. Their distance is 40^s in AR, which means that 40 seconds had gone after seeing I 25. Herschel did not realize that the western one (II 74) was actually I 25. The eastern, II 75 (NGC 4762) was indeed new. Thus, NGC 4754 was found twice. But there is another curiosity: The nebulae were found about 45' below the top of the sweep (dashed horizontal line). Why did Herschel turn down much earlier? This might be caused by a strange intuition to find more nebulae – he showed this in several situations.

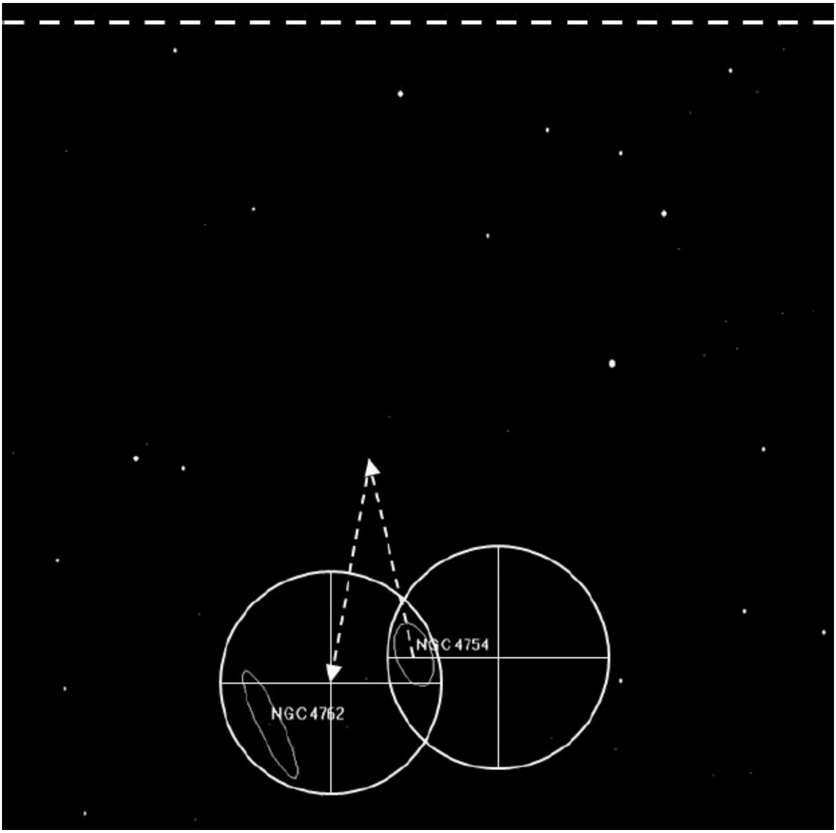


Figure 2-49: A unique case, happening on 15 March 1784: the galaxy NGC 4754 in Virgo was seen twice in a single sweep, though the elongated companion, NGC 4762, was found as usual (see text).

On 17 March, the telescope was damaged by strong wind, causing a break of two days.[418] Herschel remained calm, writing in *Journal No. 8*:

Having left my tube suspended pretty high, violent gust of wind took hold of it this afternoon & threw the whole mechanism down. The speculum was not hurt being of very tough metal. The tube was broken in many places & several parts of the apparatus much damaged, fortunately it is a cloudy evening so that I shall not loose time while I repair the havock that has been made. I suppose the weight of the whole apparatus can not be less than 11 or 12 hundred pounds.

On 19 March, Herschel observed with the repaired telescope. Cancer, Leo and Boötes were inspected in sweeps 177–179, yielding 15 new objects (all are galaxies). Curiously, M 95 (NGC 3351) in Leo is among them. Because the position is 27' northwest of the Messier object, it was not recognized and was catalogued as 'bright nebula' I 26.[419] However, in sweep 188 (12 April), he saw M 95, not mentioning I 26 now. Another interesting find was the double galaxy NGC 3020/24 in Leo (separation 6'), described as "two nebulae, both resolvable and extremely faint" (see Table 2-15).

Among the 13 objects of 21 March (sweep 181), three are remarkable. The first: "Two, very faint, pretty large, round, resolvable, both rather bright. Magnitude 240 shewed them of a considerable diameter; both are nearly in the meridian." It is the double galaxy NGC 2802/03 (III 62/63) in Cancer. With only 50" separation, it is one of Herschel's closest pairs (Figure 2-101, Table 2-28). The night also brought the faintest object, the 15.5 mag galaxy NGC 2843 (III 64): "A suspected nebula; but No. 4 shewed some small stars with suspected nebulosity; probably a deception."[420] Actually, he saw a combination of the high surface brightness galaxy with a faint star (Figure 2-50).

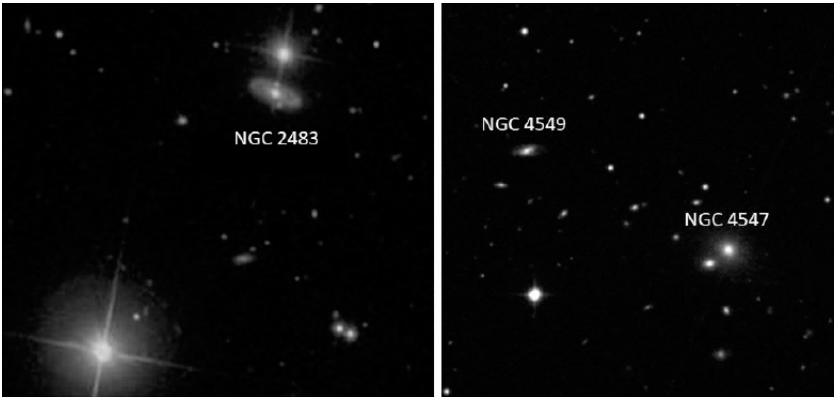


Figure 2-50: Left: Herschel's faintest object, the 15.5 mag galaxy NGC 2843 (III 64) in Cancer, found on 21 March 1784. Probably he has perceived the combination of galaxy plus 12.5 mag star, only 18" north. Right: The faintest 'single' galaxy is NGC 4549 (III 807) in Ursa Major, a companion of NGC 4547 (14.5 mag); both were seen with the front-view on 24 April 1789 (distance 4.3'). NGC 2843 and NGC 4569 are galaxies with a hight surface brightness.

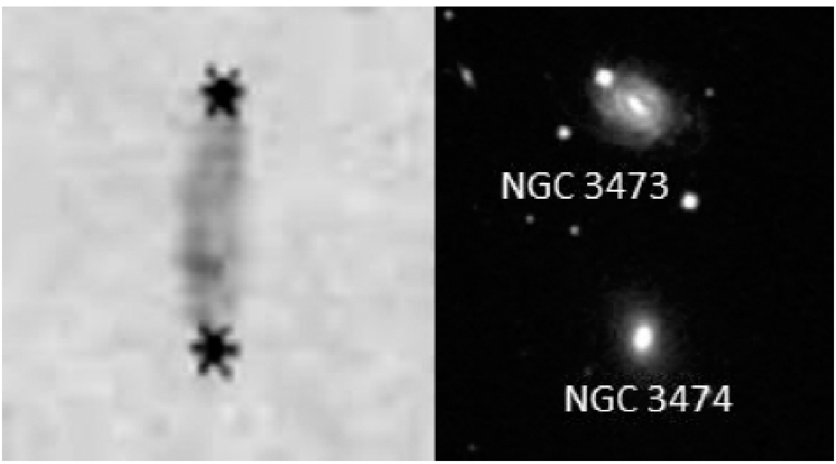


Figure 2-51: The galaxy pair NGC 3473/74 in Leo was seen as two stars, joined by faint nebulosity.

Later in the sweep, Herschel noted: "A suspected nebulosity reaching from one star to a smaller star which is about 2' south of it; 240 confirmed it." A sketch shows two stars with a nebulous envelope (Figure 2-51). He catalogued the object in Leo as 'very

faint nebula' III 67. Actually, this is a pair of galaxies with 13.5 and 14.0 mag, 1.9' apart. Dreyer lists the northern component as NGC 3473 and the southern (fainter) as NGC 3474.[421]

NGC	H	Sw	1784	Con	Type	Remarks
1896	VIII 4	78	17 Jan.	Aur	star group	
4910	V 3	123	24 Jan.	Vir	not found	Figure 2-35
5621	III 14	134	30 Jan.	Boo	not found	
1498	VII 3	136	8 Feb.	Eri	star trio	
2234	VIII 9	148	19 Feb.	Gem	star group	
5175	III 46	174	15 Mar.	Vir	star	in NGC 5174
-	III 61	181	21 Mar.	CnC	star group	
3129	III 65	181	21 Mar.	Leo	star group	

Table 2-16: Problematic Herschel objects, found in the first quarter of 1784

There are three categories of problems in the sweep data: stars, missing objects and identities (Table 2-16). In six cases, Herschel had only seen stars instead of a nebula or star cluster, and in two his object could not be identified at all. For NGC 5621 (III 14) in Boötes, he wrote: "I suspect an almost imperceptible cluster of stars or large faint nebula or nebulosity." There is no such object at the place. The star group III 61 in Cancer ("suspected a nebula") was not catalogued by Dreyer.

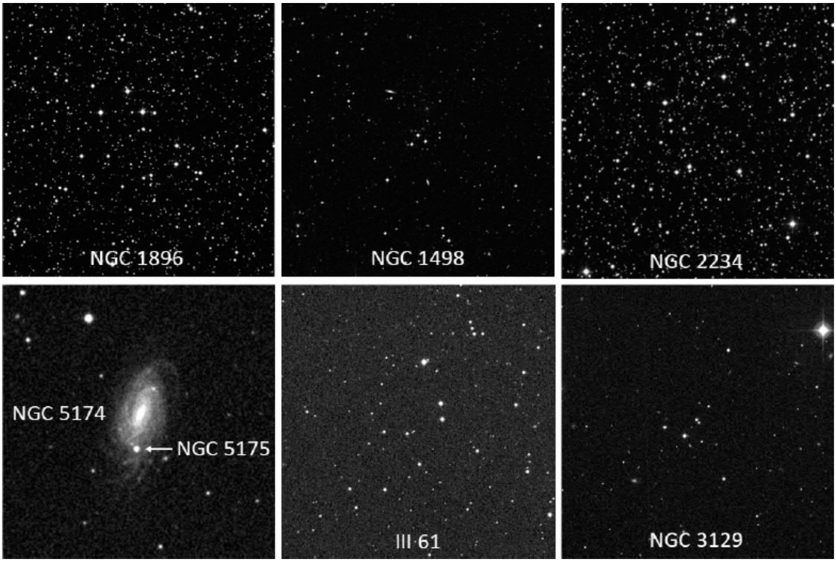


Figure 2-52: The stars and star groups of Table 2-16.

Visually it is often difficult to decide, whether a nebula has been perceived, or only a close group or pair of stars. In most cases, a higher magnification gives the answer. An example is found in sweep 218 (16 May 1784): "Suspected an extended nebulosity between two stars, but 240 shewed two double stars making a parallelogram without nebulosity." The quartet was catalogued as N5.422 In many cases, Herschel was sure that he experienced a deception. For instance, on 14 March 1784 (sweep 169): "Suspected 2 small stars, which are near each other to be nebulous; but No. 4 [240 ×] proved it to be a deception." An example of an ambiguous case gives sweep 167 (12 March 1784): "I suspected a large excessively faint nebula; but through I looked at it a good while I could not verify the suspicion, nor could I convince myself that it was a deception." The object is the 14.3 mag edge-on galaxy NGC 4529 (II 26) in Coma Berenices.

The third category of problems concerns identities between Herschel objects. There are nine cases in the first quarter of 1784. Due to the still poor positions, it was impossible for Caroline to recognise duplicate identities between objects found in different sweeps. Dreyer was not in a better situation: identical objects often received different NGC-numbers. It is already difficult to overlook a

situation in the sky visually, but it is even more difficult from the desk. Thanks to digital sky maps and reliable catalogues, we nowadays are in a much better position. With modern software tools, many identification problems can be solved. Looking at all 2500 Herschel objects, we have 50 identities between two catalogue entries, two between three entries and one between four entries (see section 5.2). Table 2-17 shows the nine cases of our period.

H1	Date1	Sw1	H2	Date2	Sw2	NGC	Con	Type	Remark
II 14	18 Jan.	85	II 60	15 Mar.	174	4119 = 4124	Vir	Gx	sketch, I 33 = NGC 4124
III 6	18 Jan.	87	I 8	23 Jan.	106	4698	Vir	Gx	2 sketches
II 23	24 Jan.	119	III 17	23 Feb.	158	4420 = 4409	Vir	Gx	sketch
II 30	15 Feb.	146	II 52	14 Mar.	170	3632 = 3626	Leo	Gx	
I 11	15 Feb.	146	I 19	14 Mar.	170	4153 = 4147	Com	GC	sketch; Figure 2-39
VI 6	8 Mar.	161	VII 6	16 Mar.	176	2355 = 2356	Gem	OC	
II 48	14 Mar.	169	II 80	21 Mar.	181	2672 + 2673	Cnc	Gx	
II 56	14 Mar.	170	II 90	21 Mar.	182	4450	Com	Gx	
I 25	15 Mar.	174	II 74	15 Mar.	174	4754	Vir	Gx	pair with NGC 4762

Table 2-17: Identities between two Herschel objects (H1, H2), found in the first quarter of 1784 (see text).

Finally, some of the problems might be due to incorrect data. Of course, Caroline's evaluation is subject to typos, wrong transcriptions or calculation errors. But considering the huge amount of information, going through her hands over the years, such cases are astonishingly infrequent. William knew about his sister's accuracy. There was a blind faith between the siblings and not much cause for criticism. Here are the few documented cases. In sweep 169 (14 March 1784) Herschel stopped observing due to strong wind. Although the last position was saved, he mistrusted the data processed by Caroline: "I should have [a correction value] which I can never ascribe to wind […] But from recollecting the impossibility of such an error, I ascribed the difference to my sister's mistake of getting down or calculating". In sweep 244 (27 July 1784), he noted: "The 30 Aquarii was probably not taken accurately by my sister." And in sweep 581 (4 September 1786) we read: "My sister making a blunder in the stars it is possible the 70th may exist." Here 70 Psc is meant.

2.2.3. The paper on the 'construction of the heavens'

The publication is titled 'Account on some Observations tending to

investigate the Construction of the Heavens'. Caroline's draft is signed 'W^{m} Herschel, Datchet near Windsor, April 1784'.[423] The manuscript was sent to the *Royal Society* and read on 17 June. It appeared in volume 74 of the *Philosophical Transactions*.[424] Here we will discuss its content relating to nebulae and star clusters, found in the still young sweeping campaign. However, the main part of the paper concerns 'star gages' and the structure of the Milky Way (see section 4.1.1). Herschel starts with a brief description of his new reflector and the observing method: "The apparatus on which it is mounted is contrived so as at present to confine the instrument to the meridional situation of a celestial object in a coarse way; which, however, is sufficiently accurate to point out the place of the object, so that it may be found again." He apologizes for the "prematurity" of the paper, but was unwilling to wait longer to present the first results of his campaign. However, Herschel starts with Messier objects, using the 7-ft, 10-ft and small 20-ft:

The excellent collection of nebulae and clusters of stars which has lately been given in the *Connoissance des Temps* for 1783 and 1784, leads me next to a subject which, indeed, must open a new view of the heavens. As soon as the first of these volumes came to my hands, I applied my former 20-feet reflector of 12 inches aperture to them; and saw, with the greatest pleasure, that most of the nebulae, which I had an opportunity of examining in proper situations, yields to the force of my light and power, and were resolved into stars.

Writing "as the first of these volumes came to my hands, I applied my former 20-foot reflector of 12 inches aperture to them" is incorrect. Herschel got the second catalogue in December 1781, not the first. Moreover, it took until 29 August 1782 to observe catalogue objects (M 52, M 57) using the 7-ft reflector, and not the small 20-ft. The latter was first pointed at an M-object on 1 January 1783; the target was M 42, the Orion Nebula.

Herschel then presents his 'Messier observations' with the 18.7-inch reflector. In his sweeps, M-objects were not on his agenda, but they occasionally passed the field of view. Of course, by the sweep plan (based on the *Atlas Coelestis*), he was prepared for them:

My present pursuits, as I observed before, requiring this telescope to act as a fixed instrument, I found it not convenient to apply it to

any other of the nebulae in the *Connoissance des Temps* but such as came in turn; nor, indeed, was it necessary to take any particular pains to look for them, it is utterly impossible that any one of them should escape my observation when it passed the field of view of my telescope. The few which I have already had an opportunity of examining, shew plainly that those most excellent French astronomers, Mess. MESSIER and MÉCHAIN, saw only the more luminous part of their nebulae; the feeble shape of the remainder, for want of light, escaping their notice.

Herschel especially celebrates his views on M 98 and M 53 of 30 December 1783 (sweep 73) and 14 March 1784 (sweep 170), respectively; see Figure 2-23 and Figure 2-44. Herschel points out the difference to the former observations of Messier (M 53) and Méchain (M 98), made with inferior telescopes. He further wrote:

When I began my present series of observations, I surmised, that several nebulae might yet remain undiscovered, for want of sufficient light to detect them; and was, therefore, in hopes of making a valuable addition to the clusters of stars and nebulae collected and given to us in the work before referred to, which amount to 103. The event has plainly proved that man expectations were well founded: for I have already found 466 new nebulae and clusters of stars, none pf which, to my present knowledge, have been seen before by any person; most of them, indeed, are not within the reach of the best common telescopes now in use. In all probability many more are still in reserve; and as I am pursuing this track, I shall make them up into separate catalogues, of about two or three hundred a time, and have the honour pf presenting them in that form to the Royal Society.

The claim of “466 new nebulae and clusters of stars” is astonishing. Looking at Caroline’s count in her first catalogue (see Figure 2-21), no. 466 is the last object of sweep 222, located at AR 17 19.9, PD 113 41 (1690). This is the globular cluster NGC 6401 (I 44) in Ophiuchus. It was discovered on 21 May 1784 – well after the closing date of “April 1784” for the manuscript. Of course, ‘466’ could have been added in proof before the paper was eventually read in June. But we know that cannot be correct, because the number appears in the original manuscript. In subsequent versions

of Caroline's catalogue the number 466 relates to even later dates, because several objects had been deleted in the meantime. By the end of March, 'only' 238 objects were actually discovered, and by the end of April there were 389. So, William's claim of 466 objects sounds strange.

At the end of the paper, Herschel develops his idea of a 'stratum'. This originally refers to a flattened layer of stars. From his star counts, he concludes that the Milky Way "undoubtedly is nothing but a stratum of fixed stars". Then the sweeping results led him to the idea of another celestial structure: a stratum of nebulae. He traced a concentration in Coma Berenices, Virgo and Leo: 70% of all nebulae discovered in the first three months of 1784, are located here. Herschel called the impressive accumulation the 'stratum of Coma Berenices' and wondered if it might perhaps "even make a circuit of the heavens", like the band of the Milky Way (Figure 2-53):

Another stratum, which perhaps approaches nearer to the Solar System than any of the rest, and whose situation is nearly at rectangles to the great sidereal stratum in which the Sun is placed, is that of Coma Berenices, as I shall call it. I suppose the Coma itself[425] to be one of the clusters in it, and that, on account of its nearness, it appears to be so scattered. It has many capital nebulae very near it; and in all probability this stratum runs on a very considerable way.

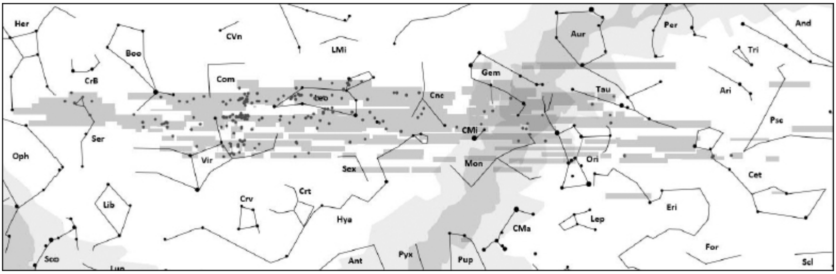


Figure 2-53: Plot of all sweeps made until the end of March 1784 (grey rectangles). Herschel's 'stratum of Coma Berenices' is shown by the crowding of objects in Coma Berenices, Virgo and Leo (small circles). Note that nearly all sweeps were made between about -5° and +30° declination (an exception is sweep 49 in Puppis).

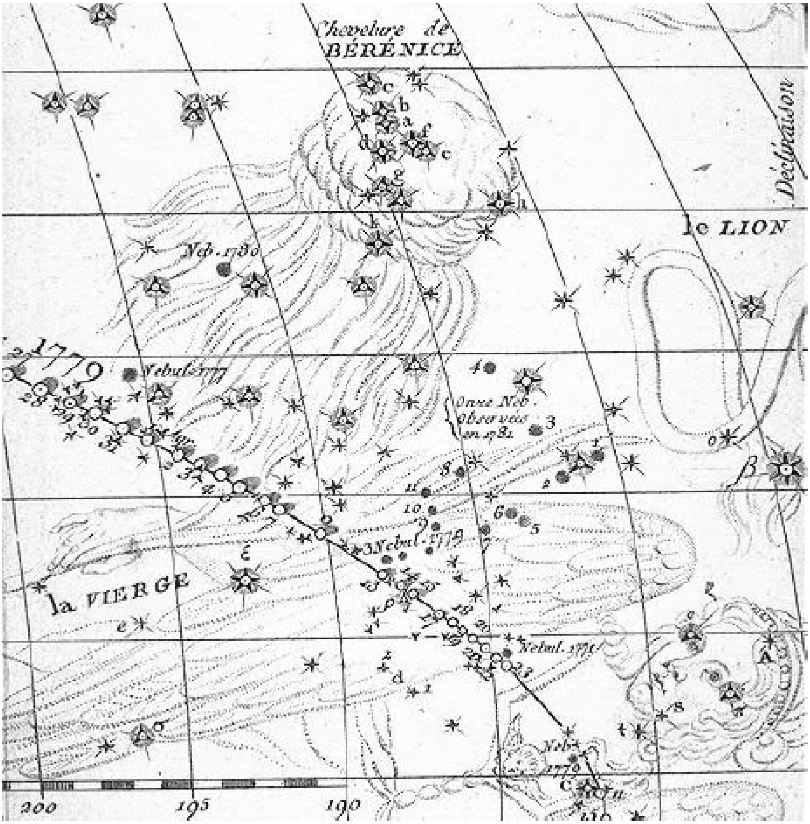


Figure 2-54: Messier’s chart of Virgo, featuring the path of Comet 1779, shows 13 galaxies of the Virgo Cluster.

Messier had already noticed an unusual concentration of nebulae in that region; it is shown on one of his star charts (Figure 2-54). In his entry for M 91, he wrote:426 “The constellation Virgo and especially the northern wing is one of the constellations which encloses the most nebulae. This catalog contains 13 which have been determined, viz. Nos. 49, 58, 59, 60, 61, 84, 85, 86, 87, 88, 89, 90 and 91. All these nebulae appear to be without stars and can be seen only in a good sky and near meridian passage. Most of these nebulae have been pointed out to me by M. Méchain.” Actually, Messier had noticed the Virgo Cluster of galaxies – and Herschel confirmed it, though based on a much larger number of nebulae (Table 2-25).

2.2.4. Second quarter – hunting the ‘stratum of Coma Berenices’

The second quarter of 1784 was no less successful than the first. Herschel’s ‘apparatus’ was working well and he was in pursuit of the ‘stratum of Coma Berenices’ to uncover its shape and extent. He mainly swept in Virgo, Coma Berenices and Leo. A total of 207 nebulae and star clusters were discovered; 177 are galaxies. April brought 151 objects in just nine nights (with the incredible number of 38 on the 13th).

Again, the observations went as long as possible, often lasting from dusk to dawn. But the task was even more arduous, since even the slightest observation possibilities were used. In the first quarter, five sweeps per night were made (on average), now only three; this meant fewer breaks.

Even the Moon was ignored. In sweep 187 on 8 April at about 11 pm we read: “The Moon appears, yet I shall continue my observations as I seem to be in the stratum of the nebulae though probably I may overlook several that are too faint and small as to require a fine dark night to be seen.” It was nearly full in Sagittarius and Herschel continued his observations for about half an hour. He was on the right track, writing on the 12th (sweep 188): “I expect to come to a stratum of nebulae, viz that of θ ι etc. Leonis.” Soon after, he encountered the well-known pair M 65/66 in Leo and discovered four other galaxies.

Unfavourable weather could not stop him either; writing on 22 April (sweep 203): “Cloudy and windy, but in search of the extent of the stratum of nebulae I endeavoured to catch a few tolerable intervals to look out for nebulae.” On the following night, Herschel noted in the *Journal*: “I shewed Dr Blagden the nebulous stratum of Coma Berenices. The was extremely troublesome & the weather was very unfavourable, we were however so far successful as to see 5 or 6 of the nebulae as they passed the meridian.” [427]

In hunting the stratum, Herschel even ignored the PD limits set for a sweep. On 25 April (sweep 208), he wrote: “To follow the stratum, I lowered and changed the situation of the telescope.”

Observing beyond these limits, can affect the position measurement negatively. The determined places in sweeps 208 and 209, made in Virgo and Libra, were marked “situation unknown” and “supposed zero 96° 44' [upper PD limit] but probably a good deal erroneous, clock unknown”. They brought two objects with unreliable positions. The first was catalogued as II 190 (NGC 4928), though the two reference stars (39 and 40 Vir) were later rejected. Although the galaxy was observed in sweeps 536 (3 March 1786) and 916 (23 March 1789), the Herschels doubted the identification. The second object, found in sweep 209, was described as “A very close compressed cluster of stars 8 or 9' in diameter, extremely rich, of an irregular figure, a little extended. The stars are so small as hardly to be visible and so accumulated in the middle as to look nebulous.” This sounds like a globular cluster; William catalogued it as VI 8. However, there is only a faint galaxy at the place in Libra: NGC 5729. Caroline later found out that, due to the undetermined situation of the telescope, the two reference stars were doubtful. However, there is a 9.5 mag globular cluster 4° northwest: NGC 5634, which is a good candidate for VI 8. Due to the (low) concentration class IV, Herschel was able to resolve it. Curiously, the object of sweep 209 was discovered again in sweep 380 on 5 March – now as ‘bright nebula’ I 70, i.e. it was not resolved. Although an identity was not noticed, there is no doubt that both objects are identical: VI 8 = I 70 = NGC 5634. Moreover, the faint galaxy NGC 5729 at the dubious place was eventually found as III 508 in sweep 522 (4 February 1786). Even John was confused by the case, but rejected the possibility that VI 8 and III 508 are identical. Dreyer also tried to identify VI 8 – and finally ignored it in the NGC.

The second quarter of 1785 was also a season of globular clusters. In total, 18 objects were found; 15 are located in Sagittarius, Ophiuchus and Scorpius. Indeed, this region with low galactic latitude is their celestial ‘home’. They are members of the galactic halo, orbiting the Milky Way. Thus, there is a natural concentration in the direction of the Galactic Centre, located in Sagittarius. Outer members were found in other constellations at high galactic latitudes, like NGC 5466 (VI 9) in Boötes.[428] The 9.2 mag globular cluster was discovered in sweep 219 on 17 May: “A large cluster of exceedingly small and compressed stars.” Like NGC 5053 in Coma

Berenices (concentration class XI), already found on 14 March, NGC 5466 has a very low star density and thus is visually a difficult object (class XII).429 As Table 2-18 shows, Herschel found objects in all concentration classes. Figure 2-55 presents the brightest exemplars of class I and XII.

CC	N	H	NGC	Date	Sw	Con	GLat	Dist	V	Remarks
I	1	I 52	7006	21 Aug. 1784	253	Del	-19°	134	10.6	'resolvable'; very distant
II	2	I 48	6356	18 Jun. 1784	230	Oph	+7	49	8.2	'easily resolvable'; distant reference star
III	1	I 45	6316	24 May 1784	224	Oph	+5°	33	8.1	'resolvable'
IV	7	VI 12	6293	24 May 1784	224	Oph	+8°	31	8.3	resolved
V	3	II 197	6544	22 May 1784	223	Sgr	+6°	10	7.5	'resolvable'
VI	6	I 50	6624	24 Jun. 1784	232	Sgr	-8°	26	7.6	'resolvable'
VII	2	II 195	6287	21 May 1784	222	Oph	+11°	31	9.3	'resolvable'
VIII	4	I 44	6401	21 May 1784	222	Oph	+4°	36	7.4	not resolved; superimposed 11.8 mag star
IX	3	I 47	6712	16 Jun. 1784	228	Sct	-4°	22	8.1	'easily resolvable'
X	3	VI 20	288	27 Oct. 1785	467	Scl	-89°	29	8.1	resolved; near the South Galactic Pole
XI	3	IV 12	6553	22 May 1784	223	Sgr	-3	20	8.3	'difficultly resolved'
XII	2	VI 9	5466	17 May 1784	219	Boo	+74	52	9.2	resolved; high galactic latitude

Table 2-18: Shapley's concentration classes (CC) for globular clusters and Herschel's discoveries (N = number of objects). The brightest exemplar in each class is given; GLat = galactic latitude, Dist = distance in 1000 light-years.

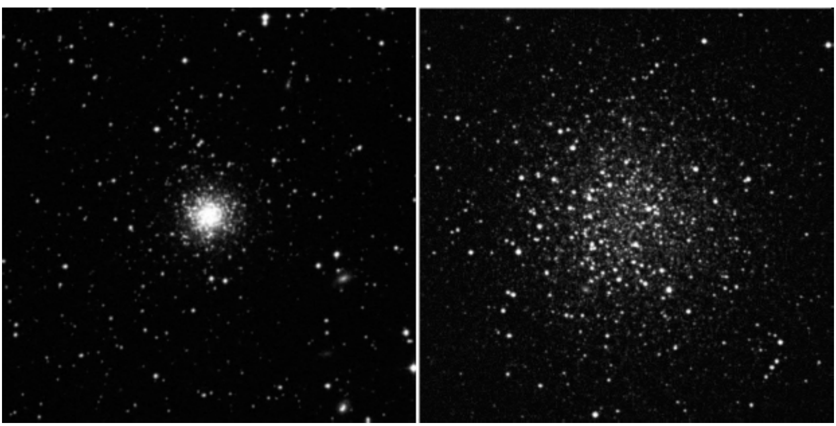


Figure 2-55: Extreme globular clusters. Left: NGC 7006 (class I) in Delphinus, a very distant object (134,000 light-years), and NGC 5466 (class XII) in Boötes, lying at high galactic latitude (+74°).

On 21 May (sweep 222), two globular clusters were found: NGC 6287 (9.3 mag) and NGC 6401 (7.4 mag) in Ophiuchus. NGC 6287 (class VII) was only seen 'resolvable' and thus catalogued as II 193. The bright cluster NGC 6401 (class VIII) was described as "pretty

large, considerably bright, having a kind of nucleus towards the following side". This is a superimposed 11.8 mag star, 18" southeast of the centre. NGC 6401 was not resolved and thus catalogued as 'bright nebula' I 44.

On 22 May (sweep 223), Herschel found a very distant globular cluster: NGC 5694 in Hydra. The 10.2 mag object (class VII) is 114,000 light-years away; it was seen 'resolvable' and thus designated II 196. A bit later, Herschel discovered a very loose globular cluster, NGC 6144 (VI 10) in Scorpius: "A very close considerably large cluster of the smallest stars imaginable; all the stars are of a dusky red colour. This cluster is the next step to an easily resolvable nebula." The object has the low concentration class XI. Later, he discovered a bright, pretty dense exemplar: NGC 6544 (7.5 mag) in Sagittarius. It was seen 'resolvable' and thus catalogued as II 197, though it is of the low class XI. Then NGC 6553 in Sagittarius was found: "pretty bright, large, difficultly resolved, the nebulosity inclining to milkyness". The 8.3 mag object was again seen two days later in sweep 224. Herschel, undecided how to qualify it, put it in the fourth class (IV 12). Though in the second lowest concentration class (XI), the globular cluster appeared not clearly resolved. This may be due to the fact that NGC 6553 was the final object on both nights. A few minutes later the sweep was terminated due to strong daylight. The night of 22 May brought also the first view of the globular cluster M 4 in Scorpius with the 20-ft: "It contains a ridge of stars in the middle running from south preceding to north following, all stars are red."[430]

24 May (sweep 224) brought two other bright, dense globular clusters: NGC 6293 (8.3 mag) and NGC 6316 (8.1 mag) in Ophiuchus. The concentration classes are IV and III, respectively. Herschel wrote about NGC 6293 (VI 12): "A miniature cluster of stars of the former cluster [M 19]; such as was described in 223 sweep, but rather coarser." Like M 19, looking "coarser" (class VIII), the globular cluster was resolved and thus designated as VI 12. For NGC 6316 we read: "bright, round, resolvable, much brighter middle, but the brightness decreasing very gradually. A faintish dusky red colour is still perceptible. A perfect miniature of the former miniature [NGC 6293]." Though the object was only 'resolvable', Herschel catalogued it as 'bright nebula' I 45. See Table

2-18 for both globular clusters.

On 16 June (sweep 228), Herschel found the 8.1 mag globular cluster NGC 6712 in Scutum: “Very large, bright, easily resolvable, with many stars visible in it; of an irregular form.” The object was catalogued as ‘bright nebula’ I 47; the concentration class is IX (Table 2-18).

Herschel expanded his declination range to observe objects down to -30°, which implied a tube elevation of only 9°. The lowest objects were discovered on 24 June (sweep 232). In the very clear night, he found NGC 6451 (VI 13) in Scorpius, just 9° above the horizon; this is his open cluster with the lowest declination (-30°). Three globular clusters in Sagittarius followed: NGC 6522 (I 49), NGC 6528 (II 200) and NGC 6624 (I 50); they were not resolved, thus not catalogued in class VI. The first two objects are only 17' apart; NGC 6522 is only 4° away from the Galactic Centre. For NGC 6624 of concentration class VI we read: “Considerably large, round, very bright middle, the brightness appears to be at least ¾ of the whole visible diameter, but I suppose if the altitude was more considerable a different proportion would be seen. The nebulosity appears of the milky kind, but from similar phenomena in low situations I have no doubt but that it is resolvable.” (Table 2-18).

Although the second quarter of 1784 was dominated by galaxies and globular clusters, it also saw other interesting objects. The most spectacular find was made on 21 May in sweep 222: Herschel discovered his famous ‘hole in Scorpius’. While star ‘gaging’ in Ophiuchus near M 80, he encountered an extreme vacant place: “So that by the Gages it seems if there were a Perforation or Hole in the body of the Scorpion.” The full story is told in section 4.1.5. When the night ended (“daylight very strong”), he noted: “A cluster of stars chiefly large ones; considerably rich, but rather coarsely scattered; a little more compressed towards the middle. It is visible in my finder.” This is NGC 6520 (VII 7), having 7.6 mag. At first glance, there is nothing unusual about it, but the vicinity offers a remarkable dark nebula, known as B 86. The object, later called Ink Spot, is located about 9' northwest.[431] Herschel missed the object by a few arcminutes. Otherwise, he could have discovered another ‘hole’ in the sky.

Among the galaxies, we have 18 pairs and seven trios. Most of them belong to Herschel's 'stratum'. Three pairs are members of the Markarian Chain, right in the centre of the Virgo Cluster (Figure 2-56).[432] Starting at M 84 and M 86, we encounter the pairs NGC 4435/38 and NGC 4458/61 (II 121/22) and the trio NGC 4473/77/79 (III 114–16). The new objects were discovered in two April nights, on the 8th (sweep 187) and 12th (sweep 189). Except NGC 4438, all were catalogued. In this case, Herschel saw "Two resolvable nebulae at 4 or 5' distance." Caroline later added that "one is M 86" and, consequently, only NGC 4435 (I 28) was catalogued. However, the identification with M 86 is wrong; the Messier object is 23' southwest of the pair. Herschel has actually seen NGC 4438, later identified by John, who introduced the designations I 28,1 and I 28,2 for NGC 4435/38. The stunning pair is known as The Eyes. The trio NGC 4473/77/79 was discovered shortly after. The bright galaxy M 86 was first seen in sweep 199 (17 April), together with M 84 (17' west).[433] In sweep 200 (same night), Herschel found the very close pair NGC 5953/54 (II 178/79) in Serpens. The galaxies are 46" apart (Figure 2-101, Table 2-28): "Two very small nebulae, very near each other; the southern one is the largest and their nebulosities run into each other. 240 confirmed it."

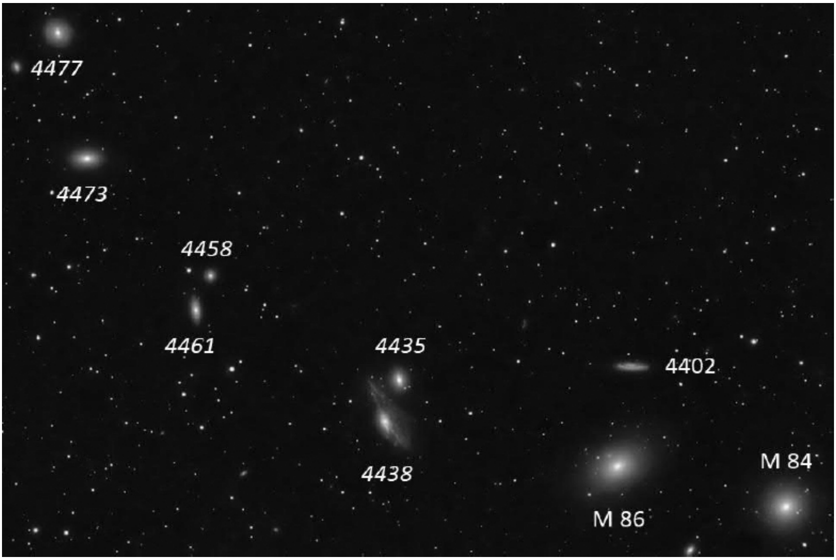


Figure 2-56: The famous Markarian Chain of galaxies in the centre

of the Virgo Cluster bears interesting pairs.

On 16 May (sweep 218), Herschel discovered his most distant galaxy, NGC 5699 in Boötes. The small 14.2 mag object with a high surface brightness is 978 million light-years away. There is a companion, seen in the same field: the elongated 13.6 mag galaxy NGC 5703, 'only' 170 million light-years away. Figure 2-57 shows the optical pair, together with Herschel's nearest object: the open cluster NGC 2232 in Monoceros.

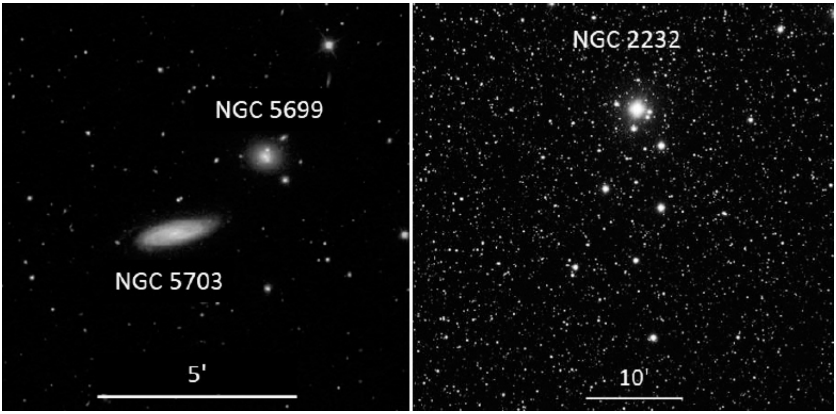


Figure 2-57: Left: Herschel's most distant object, the galaxy NGC 5699 (14.8 mag) in Boötes, is 978 million light-years away; with 170 million light-years, NGC 5703 (13.9 mag) is a foreground object. The pair were found on 16 May 1784. Right: With a distance of 1060 light-years, the open cluster NGC 2232 in Monoceros is his nearest object; seen on 5 December 1779 with the 7-ft, it was also his first non-stellar find (the 5.0 mag star is 10 Mon).

Between April and June, Herschel observed 32 Messier objects. The best nights were in April: both the 8th and 12th brought six objects, and the 17th eight. Ten Messier objects were seen for the first time: M 54, M 64, M 80, M 84, M 87–91 and M 99.

The face-on spiral galaxy M 99 in Coma Berenices was the first object observed on 8 April (sweep 187): "A large pretty bright resolvable nebula. Too much moon light to describe it more particularly." A better view did not come until 14 January 1787 (sweep 691): "Very bright, very large, very gradually much brighter

middle, and the brightness taking up a great space." It is remarkable that Herschel did not recognise the spiral structure, later so clearly seen by Lord Rosse – though with a 72-inch reflector.

An even more striking case is M 51 in Canes Venatici, known as the Whirlpool Nebula. Herschel saw the large face-on galaxy first on 12 May 1787 (sweep 734) with the 18.7-inch and again on 29 April 1788. No spiral structure was recognized on either date. The reflector was not too small, but the feature was at its optical limit and, even more importantly, Herschel was not prepared for it. Unfortunately, he never tried the 48-inch telescope on M 51 and M 99. Otherwise, he would surely be praised as the discoverer of spiral nebulae, instead of the later Birr Castle astronomer.[434] Lord Rosse's drawings of the spiral galaxies are shown in Figure 2-58.

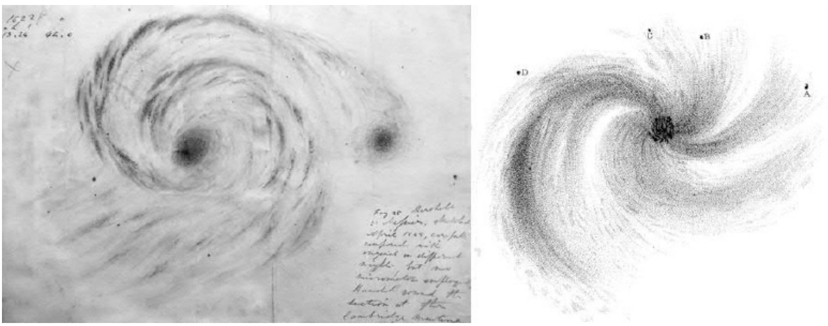


Figure 2-58: Lord Rosse's drawings of the spiral nebulae M 51 and M 99, made with the 72-inch Newtonian reflector at Birr Castle on 6 April 1845 and 11 March 1848, respectively.

The night of 8 April (sweep 187) brought further remarkable observations in the context of spiral structure. A third object was added to the pair M 65 and M 66 in Leo: the 9.5 mag edge-on galaxy NGC 3628 (V 8), only 35' north. The striking ensemble is known as the Leo Triplet (Figure 2-59). Herschel wrote about the 'large nebula' V 8: "A bright, very much extended nebula; it is a little brighter in the middle than towards the ends. It seems to extend 9 or 10' if not more." M 65 was not observed in the sweep, but M 66: "A very bright, much extended nebula; much brighter in the middle than in its two faint branches which run out farther than my field of view can take it. I think it is of the resolvable kind but

will not stay long enough to be certain of it. It is Messiers 66 but that Gentleman [Messier] could not see its branches they being much too feeble for his light."

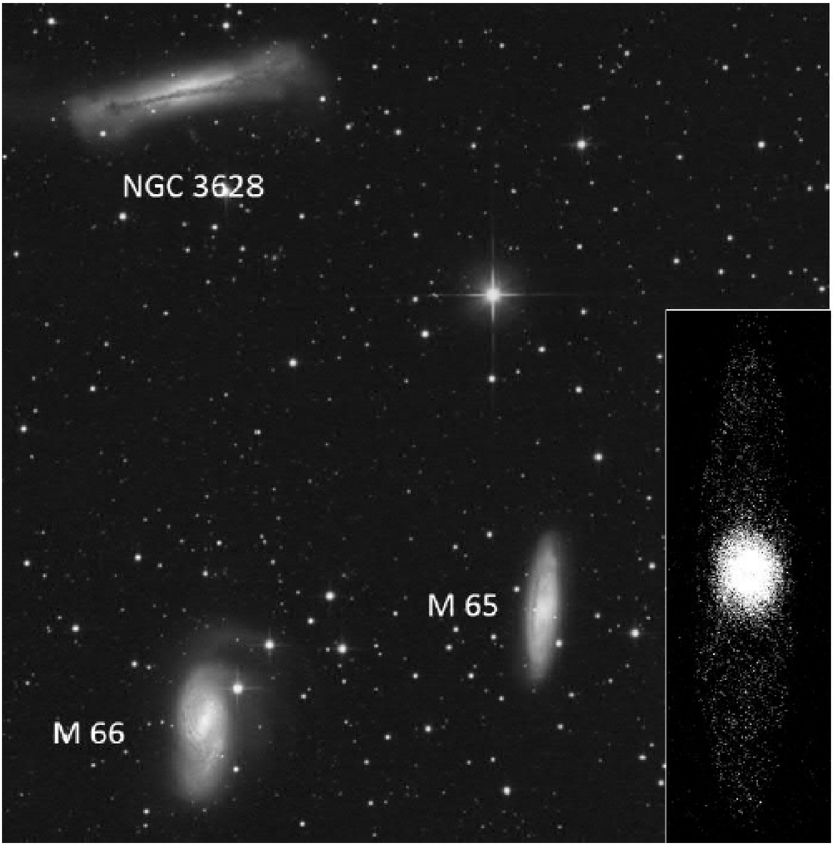


Figure 2-59: The stunning galaxy group known as the Leo Triplet. Its northern member, the 9.5 mag galaxy NGC 3628, was discovered on 8 April 1784. Inset: Herschel's sketch of M 65, made on 24 February 1786.

What is meant by the "two faint branches"? Actually, M 66 is a two-armed spiral galaxy. Did Herschel possibly see spiral arms in this case? All three galaxies were observed in sweep 188 (12 April). M 66 is described as: "A very bright much extended nebula of an irregular figure, the extension is chiefly in the direction of the meridian, and the greatest brightness near the middle." But now he speaks about 'extensions' instead of 'branches'. It is interesting, to

read his note on NGC 3628: "A bright very much extended nebula. The extent is not far from the parallel [east-west direction]. The faint branches are longer than the field can take in." In the description of M 65, seen about 25° from the side, these terms are missing. Herschel has perceived M 66 and NGC 3628 to show a bright central part plus radial 'extensions'.

The Leo Triplet was viewed again on 24 February 1786 (sweep 531). Nothing is said about 'branches' or 'extension' of M 66 and NGC 3628, but for M 65 we now read:[435] "Very brilliant, extended in the meridian, 12' long, a bright nucleus, suddenly diminishing and the branches very faint." This leads to the conclusion that Herschel's 'branches' cannot be interpreted as spiral arms – they were never seen. The 'extensions', coming out from the nucleus in opposite directions, are due to the tilted view of the disk of the spiral galaxy.[436]

Another Messier galaxy was seen in the night of 8 April, M 91 in Coma Berenices, though not identified as such. Herschel catalogued the object as II 120. Even at a second observation (sweep 691, 14 January 1787) the identity with M 91 was not recognized. But he cannot be blamed, because the French astronomer gave an incorrect position, about 1° southeast of the galaxy.[437] M 91 is not plotted in the *Atlas Coelestis*. Moreover, observing in this part of the sky, with so many nebulae, identifying them was not an easy task.

Herschel is also innocent in another case: M 104. He found the 8.0 mag object in Virgo, known as the Sombrero Galaxy, in sweep 210 on 9 May: "An extended nebula; very bright in the middle; about 5 or 6' long but day is too strong to see the whole of it. The bright place in the middle is pretty large but breaks off abruptly." Obviously, Herschel has noticed the dark absorption lane. Though discovered by Méchain on 11 May 1781, M 104 was unknown to Herschel, as it wasn't added to the *Messier Catalogue* until 1917.[438]

M 80 is a globular cluster in Scorpius. In sweep 212 (11 May), Herschel noted: "A very bright & considerable large round nebula; brightest in the middle & the brightness diminishing very gradually; about 4' in diameter; no signs of its being resolvable but that may be owing to the low situation. I should suppose this nebula may be seen in the 3½ft achromatic. On comparing it with the nebulae of

the Connoissance des temps, I find it to be the 80th." The very compact object (concentration class II), standing only 16° above the horizon, was not noticed as a globular cluster.

Before starting sweep 224 on 24 May, Herschel observed the 8.2 mag galaxy M 64 in Coma Berenices, using the 10-ft reflector at 235×.[439] He noted: "It has a large nucleus and resolvable nebulosity. Very large & of an irregular shape." M 64 is known as the Black Eye Galaxy (see Figure 2-142).

In sweep 230 (18 June), Herschel discovered the 8.2 mag globular cluster NGC 6356 (I 48) in Ophiuchus: "A large, bright, round, easily resolvable nebula. brightest in the middle & the brightness diminishing gradually. It is a miniature of the last [M 9], and I suppose if I had looked long enough I might have perceived some of the stars that compose it." Due to its compactness (concentration class II), it was not resolved and was classified as a 'bright nebula' (see Table 2-18). Although the reference star (43 Sgr) is about 27° east, Herschel's position is very good.

On 24 June (sweep 232), the 7.7 mag globular cluster M 54 in Sagittarius was observed: "A round, resolvable nebula." The object was only 8° above the horizon. In this night another innovation came to use: "I applied a small Birds quadrant with a spirit level fastened to the movable telescope; and adjusting it to the zero at the beginning of the sweep found it required an alteration of about 18' to restore the level when I left off; which agrees perfectly with the observations of p [3] & ζ Sagittarii."[440] The quadrant (Q) measures the difference between zenith and elevation (E), i.e. Q = 90° - E (see Figure 2-2). The value determines the altitude of the tube, formerly obtained by a star identified in the finder. In 1786, Herschel explained the function of the new device:[441]

In June, 1784, I introduced a small quadrant of altitude, the use of which became soon after of the greatest consequence in determining the value of the numbers of the polar distance piece. Hitherto I had settled this value by causing a star to pass vertically through the field of the finder, which was very accurately limited to two degrees; but now I found, by many comparisons between the degree determined by the quadrant and by the finder, that I had generally under-rated the value of the numbers. Fortunately so

many stars of FLAMSTEED'S Catalogue had been taken, that the numbers between their different polar distances were sufficient to recover the value of the degree; but this occasioned a laborious recalculation of the places of all objects taken in near 300 sweeps. The quadrant being once introduced, I carried the refinements of the determination, in high sweeps where the ropes acted very unequally, so far as to ascertain by it separately the value of every 20 or 30 minutes throughout the whole breadth of a sweep of two degrees, and the numbers were then accordingly cast up by so many different tables calculated on purpose.

On 11 October (sweep 288), Herschel noted: "I found now that the degree might be much better ascertained by the quadrant than with the finder; but supposing that it was necessary, in order to be accurate not to let the tube remain long in the same place, I hardly suffered the bubble to be settled, but remained only about as long in one position as I imagined the taking the transit of a star might last." The term 'degree' should be explained. For the calculation of the PD of an object, the index value corresponding to the standard breadth of 2° must be known (see Table 2-13). It depends on altitude; the index scale is divided into 100 numbers. In that night, Herschel measured "By the finder 86 = 2°" and "By Quadrant 76 = 2°". It is further interesting that he did not waste time on stars. Recording a transit should be made as quick as possible during the 'sweeping motion'. This is different from observing a non-stellar object. To examine it, the motion was stopped and Herschel followed the object by the 'side motion'.

A remarkable discovery was made in sweep 191 (13 April): three galaxy trios in Virgo, arranged roughly in a chain. The first is NGC 4326/33/39 (II 141–43), lying within 6'. About 1° north we find NGC 4341/42/43 (III 95/96/94) within 10'. Interestingly, only the brightest member, NGC 4343 (12.1 mag), was seen in sweep 498 (28 December 1785).[442] The third trio is located 25' northeast, NGC 4365/66/70 (I 30/III 97/II 144) within 12'. The brightest galaxy is NGC 4365 with 9.6 mag; the faintest is NGC 4366 with 14.3 mag. Sweep 191 brought 35 galaxies, most of them in Virgo. Sometimes, when in a hurry, Herschel was irritated. After he discovered NGC 4423 (II 145) in Virgo, he saw NGC 4430 (II 146): "I suspect this to be the same nebula with the last but one which was observed when

the telescope went down and this while it came up, however I am not sure of it. The difference of 0',4 in time

[0.4^{m}] and 3' in PD is not sufficient to determine this point as they were both taken in a hurry.” Actually, these are separate objects: NGC 4430 is 23' north of the galaxy NGC 4423 (Herschel’s differences are not reliable). The problem is caused by his sweeping method (see section 5.1). NGC 4423 is one of two edge-on galaxies with axis ratio 6, found in sweep 191. The other is NGC 4197 (II 134). Less extreme is the 10.9 mag lenticular galaxy NGC 4570 (I 32). It was again observed in sweep 498: “Considerably bright, small, a bright nucleus and two very faint branches.” The two symmetric parts of the nearly edge-on disk, starting at the centre, were perceived as ‘branches’. The sweep yielded two more interesting objects in Virgo. The first is the close pair NGC 4296/97 (II 92/93) with a separation of only 1' (NGC 4297 has a high surface brightness). The other is the face-on galaxy NGC 5210 (III 99); it was sketched.[443] Another nebula, found in sweep 191, served as a template for a sketch: the 12.8 mag galaxy NGC 5239 (III 101) in Boötes (Figure 2-60).

Figure 2-60: The 12.8 mag barred spiral galaxy NGC 5239 in Boötes, seen face-on; Herschel discovered it on 13 April 1784.

Herschel discovered a stunning trio of edge-on galaxies in Virgo, lying almost in a line, stretching over 23' from southeast to northwest. They were not found at the same time. The upper component, NGC 4222 (II 109), appeared in sweep 187 (4 April);

the two others in sweep 199 (14 April), NGC 4206 (II 165) is the lowest and NGC 4216 (I 3) in the middle, being the brightest member. NGC 4206 and NGC 4222 have axis ratios of 6.

Herschel saw two edge-on galaxies in April: NGC 4302 (II 112) in sweep 187 and NGC 4197 (II 134) in sweep 191, with axis ratios of 5 and 6. The 11.3 mag galaxy NGC 4302 is 2.3' east of NGC 4298 (II 111) with 11.6 mag. The spectacular pair is described as: "Two resolved nebulae the 1st round the 2nd elongated, about 2' distant from each other." Sweep 187 yielded two other galaxies: NGC 3489 (II 101) in Leo and NGC 4262 (II 110) in Coma Berenices.[444]

The 13.2 mag galaxy NGC 3356 in Leo, discovered as III 107 on 17 April (sweep 196) is remarkable: "Suspected, excessively faint, pretty small. Too much daylight remaining to verify it; but I do not much doubt it." However, a second observation on 28 December 1785 (sweep 497) brought something different: "Looked for the 1st nebula of 196 sweep and am pretty sure it does not exist; as the morning is very favourable." The object was eventually confirmed on 12 April 1801 in sweep 1098.

Beside galaxies and globular clusters, the second quarter of 1784 brought a planetary and an emission nebula.[445] The former is NGC 6369 (IV 11) in Ophiuchus, shining at 11.4 mag and found in sweep 222 (21 May): "A curious, round, tolerably defined pretty bright nebula 30 or 40" in diameter." This is Herschel's (true) planetary nebula with the lowest declination (-24°). John classified NGC 6369 as an 'annular nebula', though his father never used this term.[446] The emission nebula is NGC 6526 (V 9) in Sagittarius, found in sweep 223 (22 May). The object is involved in the strange case of Herschel's M 8 observation (see section 2.2.6).

No sweep was made between 24 May and 11 June. There is no obvious reason for this break of 18 days. It was probably due to bad weather.

Finally, one should mention Herschel's observation of M 17 on 22 June (sweep 231). This is the prominent Omega Nebula in Sagittarius, previously viewed twice with the small 20-ft in 1783.[447] Now he wrote:

A wonderful nebula. Very much extended, with a look on the preceding side; the nebulosity of the milky kind; several stars visible in it, but they seem to have no connection with the nebula which is probably far more distant. I saw it only thro' short interval of flying clouds and haziness; but the extent of the light including the hook is above 10 minutes. I suspect besides that on the following side it goes on much farther and diffuses itself towards the north & south. It is not of equal brightness throughout, and has one or more places, where the milky nebulosity seems to degenerate into the resolvable kind. Such a one is that just following the hook towards the north. Should this be confirmed in a very fine night, it would bring on the step between these two nebulosities which is at present wanting, and would lead us to surmise that this nebula is a stupendous stratum of immensely distant fixed stars some of whose branches come near enough to us to be visible as resolvable nebulosity, while the rest runs on to so great a distance as only to appear under the milky form. It is the 17th of the Connoissance des temps.

Of course, this long description cannot be shouted to Caroline's desk. Indeed, her record in *Sweeps No. 3* is much shorter: "a wonderful nebula; the nebulosity of the milky kind, several stars within it; but they seem to have no connection with it, interrupted by clouds." The sweep ended half an hour later and William had time to write down the details of his observation. Moreover, it is interesting that he again speaks of a 'stratum', now of "immensely distant fixed stars". M 17 was again observed, under better conditions, on 27 June 1786 (sweep 576); no new information resulted.

2.2.5. Third quarter – Barthélemy Faujas de Saint-Font visiting Datchet

The third quarter of 1784 was again a very successful, but strenuous period. Herschel swept on 68 nights and discovered 251 objects. 198 are galaxies, mainly located in Pegasus and Pisces. Of course, there are some pairs and trios among them. The rest: 17 open clusters, eight emission/reflection nebulae, six planetary nebulae and five globular clusters. Moreover, 16 new double stars and three garnet stars were detected.[448] Again, Messier objects were viewed

with the 18.7-inch in the sweeps.

On 13 July (sweep 237), Herschel observed at very low declinations; the tube elevation was only 6.4°. M 6 in Scorpius, known as the Butterfly Cluster, and the globular clusters M 54, M 55, M 69 and M 70 in Sagittarius were seen (the latter two for the first time). Another globular cluster, NGC 6569 (II 201) in Sagittarius, was discovered. It is among Herschel's objects with the lowest declination (see Table 2-51 and Figure 2-181). However, this was not the absolute minimum for the 20-ft: on 27 September 1793 (sweep 1053), the tube elevation was only 5.1°. Herschel observed the 4.3 mag star ι PsA ($\delta = -33° 56'$). Only the double star N101 in Microscopium was found in the sweep. Already on 3 May 1783, Herschel had observed the open cluster M 7 in Scorpius with the 4.2-inch sweeper, standing only 2° above the horizon. But this all was topped by a day observation to correct the quadrant, made on 9 October 1784.[449] Herschel pointed the telescope to "an object on the Hill, altitude 1° 0'." The tube opening was only 4 inches above the ground.

On 15 August 1784, Barthélemy Faujas de Saint-Font (Figure 2-61) spent a night at the Herschels', while touring England; his entertaining travel report was published in 1799.[450] A few days earlier he had already met William at Greenwich: "I was introduced to this illustrious astronomer, and I had some hopes that he would not refuse me the favour of seeing the large telescope in his observatory in Windsor Forest."

Figure 2-61: The French geologist Barthélemy Faujas de Saint-Font made a stop at Datchet on 15 August 1784, while touring England.

Faujas arrived at Datchet most likely at 9 pm and left the next morning at 8 am. At 8:45 pm, Herschel had started sweep 250 with “a great deal of daylight left yet”. Due to the scholarly visitor, the sweep was terminated at 9:25 pm and was marked by Caroline as

‘half swept’. Parts of Hercules were observed in the clear night; her sweep record (‘Original’) mentions two unknown stars and four gages.

Faujas witnessed the sweep in Caroline’s room, next to the telescope, for about 20 minutes. Then William devoted himself to his guest, showing him the telescopes and several celestial objects. However, Faujas’ report, presented below, cannot be correct in all its details (problematic point are underlined and discussed below).

I arrived at Mr. Herschell’s [sic] about ten o’clock. I entered by a staircase, into a room which was decorated with maps, instruments of astronomy, and natural philosophy, spheres, celestial globes, and a large harpsichord.

Instead of the master of the house, I observed, in a window at the farther end of the room, a young lady seated at a table, which was surrounded with several lights; she had a large book open before her, a pen in her hand, and directed her attention alternately to the hands of a pendulum-clock, and the index of another instrument placed beside her, the use of which I did not know: she afterwards noted down her observations.

I approached softly on tiptoe, that I might not disturb a labour, which seemed to engage all the attention of her who was engaged in it; and, having got close behind her without being observed, I found that the book she consulted was the Astronomical Atlas of Flamstead [sic], and that, after looking at the indexes of both the instruments, she marked, upon a large manuscript chart, points which appeared to me to indicate stars.

This employment, the hour of the night, the youth of the fair student, and the profound silence which prevailed, interested me greatly. At last she turned round her head, and discovered how much I was afraid to disturb her; she rose suddenly and told me she was very sorry I had not informed her of my arrival, that she was engaged in following and recording the observations of her brother, who expected me, and who, in order that he might not lose the previous opportunity of so fine a night, was then busy in his observatory.

“My brother,” said Miss Caroline Herschel, “has been studying these *two hours*; I do all I can to assist him here. That pendulum [clock] marks the time, and this instrument, the index of which communicates by strings with his telescopes, informs me, by signs which we have agreed on, of whatever he observes. I mark upon that large chart the stars which he enumerates, or discovers in particular constellations, or even in the most distant parts of the sky.”

This fraternal communication, applied to a sublime but abstruse science, this constancy of study during successive nights, employed in great and difficult observations, afford pleasing examples of the love of knowledge, and are calculated to excite an enthusiasm for the sciences, since they present themselves under an aspect so amiable and so interesting.

Mr. Herschel’s observatory, to which I repaired some moments after, is not built on an eminence, nor on the top of a house; he has preferred placing it on a verdant plain, where the wind is not so likely to shake his instruments, and which is sufficiently extensive to permit all the motions such large machines require.

If Faujas arrived at “ten o’clock”, Herschel’s sweep had been over for more than half an hour. How could Faujas have ‘tiptoed’ in while Caroline was working as described if the sweep was over? Did he come earlier? Certainly not according to Faujas. In a former remark, he wrote: “At seven in the evening […] I took leave of Sir Joseph, and set on to meet William Herschel, who expected me. […] The house in which Mr. Herschel makes his observations stands at one end of the forest of Windsor, and is about 20 miles distant from the house of Sir Joseph Banks; but, with good horses, and in an English chaise, the journey may be performed in three hours.” Caroline’s supposed words “My Brother has been studying these two hours” do not fit either, because the sweep barely lasted 40 minutes. After such a long night, Faujas almost certainly put off writing his long narrative till later; and he probably misremembered some of the details of his visit.

It is interesting that Flamsteed’s atlas is mentioned. Obviously, the bulky item was used to identify the observed stars in the sweep zone. It measures 24″ × 19″ and was even larger than the page size

of the register sheets (18.5" × 14.5"). It is also interesting that the PD string was used for specific communication, in addition to measuring PD. What is meant by the remark "that, after looking at the indexes of both the instruments, she marked, upon a 'large manuscript chart', points which appeared to me to indicate stars"? This was interpreted in the literature that Caroline "must have been able to derive polar distance directly from the Index [because] Faujas clearly describes Caroline plotting stars and nebulae directly onto the map".[451] This would mean that she directly saw the AR and PD of an object at her desk, which could then be entered immediately into a sky chart. This is a misinterpretation for several reasons. If there actually were a PD coordinate, what about the AR? This could be derived only later, by a reference star. At the time of observation there was only a sidereal clock reading. Anyway, a PD could not be read from a device ('PD clock') until 24 September 1785.

Moreover, which "large manuscript chart" could be meant? This cannot be Caroline's 'Object chart', for nothing was discovered that night. Known stars also makes no sense. Only two 'unknown stars' were encountered (U^{214}, U^{215}); for them, the *Atlas Coelestis* had to be consulted, which again needed a determined position. However, four 'star gages' were performed in the sweep, shown in the record. Caroline entered them directly into the 'Register of Gages'. This was possible because there was no need for positional accuracy. She simply took the sidereal time for the AR; the mean PD of the sweep was known and the PD index gives the deviation.

It is not surprising that the 'Register of Gages' actually shows four numbers at the rough position (Figure 2-62). These are the numbers of the counted stars. Thus, what Faujas watched, were these entries!

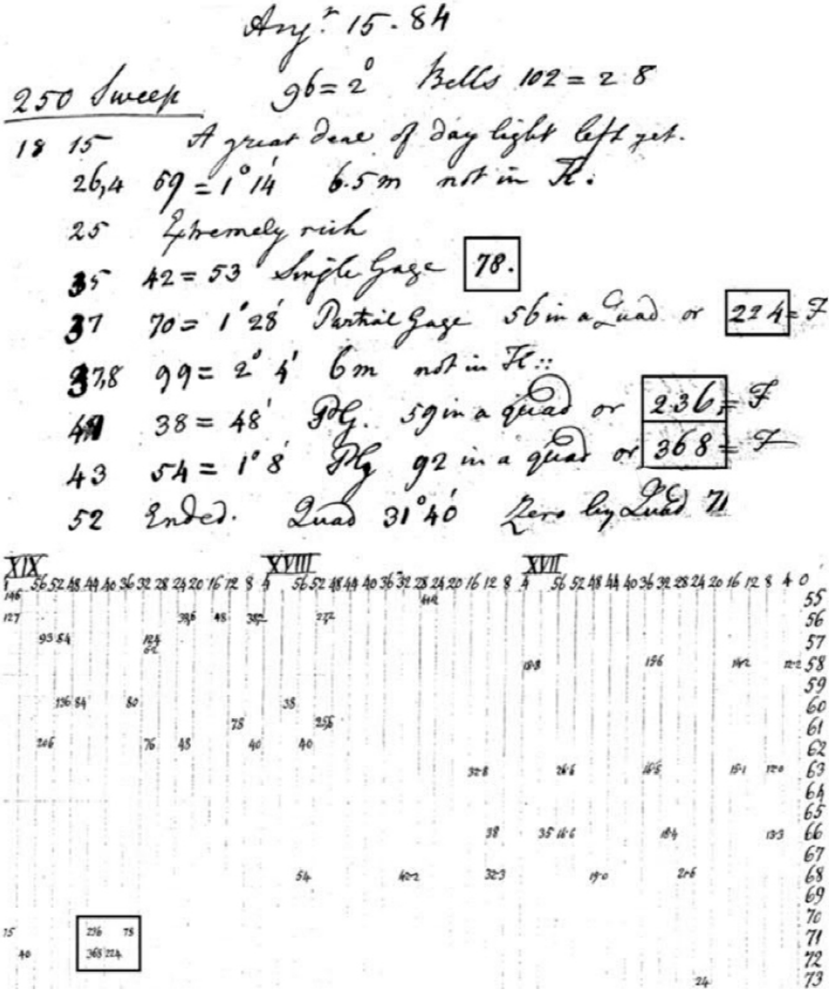


Figure 2-62: Sweep 250 of 15 August 1784 ended after 40 minutes due to the arrival of Faujas (note the sidereal time in the record). The counted star numbers of the four gages (see rectangles), made in sweep 250, were entered by Caroline in the 'Register of Gages' (below) at their rough positions (marked by the rectangle).

Faujas further wrote (problematic points are underlined):

His telescopes are elevated in the air, and mounted in a most simple and ingenious manner: a young man is placed in a kind of chamber below, who, by means of machinery, turns the telescope and the

observer together in a circle, with a gradual motion corresponding to that of the earth; thus the reflexion of the star observed is retained on the metallic mirror.

These large machines are, besides, constructed with that precision, solidity, and care, which renders them capable of bearing the intemperateness of the air; and the mirrors are so disposed, that they can be taken out and replaced at pleasure, notwithstanding they are of considerable weight.

Obviously, the ”young man” (workman) controlling the ‘sweeping motion’, was placed in a “kind of chamber” below the telescope. However, the following statement, that he turns “the telescope and the observer together in a circle, with a gradual motion corresponding to that of the earth” is misleading. There was no azimuthal tracking of the whole telescope. Maybe Faujas has misunderstood Herschel, who meant the ‘side motion’ which keeps the object in the field of view a few minutes. Nevertheless, it interesting that the “chamber” was fixed on the construction and could be rotated with it (‘round motion’). Actually, the 40-ft shows such a hut, but there is no figure of the 20-ft, which could prove Faujas’ statement.

The visitor now tells us that he had the pleasure to observe with Herschel’s 7-ft for two hours, though there is no note about it. The 10-ft and the two 20-ft reflectors (12-inch, 18.7-inch) were shown to him.

Here I saw that ever-memorable telescope with which the eighth planet was discovered. M. Herschel gave to it the name of the King of Great Britain [George III], and called it *Georgium Sidus*. But all astronomers, actuated by a feeling of general gratitude, have, with one unanimous voice, unbaptised it, and given it the name of *the planet of Herschel* [italics by Faujas].

This telescope, with which I had the pleasure of making observations during two hours, is only seven feet long, and six inches six lines in diameter. Mr. Herschel assured me, that he had made more than one hundred and forty mirrors with his own hands, before he reached that degree of perfection, to which he at last brought them. A telescope of ten feet length is placed beside this

one.

This celebrated astronomer has not confined the size of his telescopes to the last measure; there are two others, which are twenty feet long, mounted on large standards rising above the house. The diameter of one of these telescopes is eighteen inches three-fourths, and the mirror weighs one hundred and fifty pounds.

As these superb instruments are of the Newtonian kind, which requires the observer to be beside the object-glass, Mr. Herschel has constructed an apparatus of ingenious mechanism, by which the farther end of the telescope can be reached with ease and safety. There the observer finds a turning chair so disposed, as to enable him to sit at his ease, and follow the course of the stars. A domestic, placed below the telescope, by means of an ingenious combination, moves it softly and gradually along with the observer, and all the apparatus.

Thus William Herschel has been enabled to discover, distinctly, those innumerable stars, which form the most pale and distant parts of the galaxy.

The remark about a "turning chair" is interesting. This confirms that there was no gallery in August 1784, but the movable chair at the side of the tube. As previously noted, the chair was already installed in January. We further read:

With these instruments he has been enabled to observe that multitude of double stars, as well as so many nebulae, with respect to which astronomers had only vague and uncertain notions; with them, too, he has undertaken to count the stars of the sky, and has made most astonishing discoveries.

Placed at the upper end of his telescope, when the indefatigable astronomer discovers in the most deserted parts of the sky a nebula, or a star of the least magnitude, invisible to the naked eye, he informs his sister of it, by means of a string which communicates with the room where she sits; upon the signal being given, the sister opens the window, and the brother asks her whatever information he wants. Miss Caroline Herschel, after consulting the manuscript tables before her, replies, brother, search near the star Gamma, near

Orion, or any other constellation which she has occasion to name. She then shuts the window, and returns to her employment.

That man must be born with a very great indifference for the sciences, who is not affected by this delightful accord, and who does not feel a desire that the same harmony should reign among all those who have the happiness to cultivate them. How much more rapid would their progress then be!

We commenced our observations with the *Milky-way*.

The telescope of twenty feet discovered to us, in the palest and most distant part of the heavens, an immense number of bright stars, quite distinct and separate from each other.

Mr. Herschel then directed the instrument to the star in the foot of the Goat, which emitted so strong a light as to affect the eye. On making its light fall upon a paper written in very small characters, we could discern and count the lines with ease. It is curious thus to distinguish objects by the glimmering of a star, that is, a sun many hundreds of millions of miles removed from the confines of our system.

Again the 'string communication' between the siblings is mentioned ("upon the signal being given, the sister opens the window, and the brother asks her whatever information he wants"). Of course, "Gamma, near Orion" is only an example; such an object, whatever it should be, was not observed that night. The "star in the foot of the Goat" is Fomalhaut. Faujas continues:

The double stars, which are not visible with the most powerful acromatic [sic] glasses, appear separate and very distinct, when viewed with the telescope of twenty feet long. Mr. Herschel made me observe the nebulae of M. Messier, at first with the telescope of seven feet, that is, the one which served to discover the planet. These little specks appear still nebulous with that instrument; and one perceives only a feeble and obscure glimmering. But the telescope of twenty feet permits one no longer to doubt that they are clusters of stars, which appear confused only because of their immense distance; by this telescope they are found to be perfectly distinct.

Mr. Herschel requested me to direct my principal attention to the stars which he was the first to discover to be of different colours from each other, and among which some are seen which border on blue, others on orange, and several on a bluish colour, &c.

It is certainly neither to an optical illusion, nor to the effect of the mirrors and lenses, which Mr. Herschel uses, that we ought to attribute this difference of colour. I started every possible objection upon the subject; but the learned observator always answered them by facts, to which it would be unreasonable to reply. Thus, for example, he repeatedly directed the telescope to two double stars of pretty nearly the same magnitude, and separated from each other by a small interval only; that is, small in appearance, for the interval must be immense if we consider their distance from earth. Both were of the same colour, and emitted the common white light of the stars.

On directing the same telescope immediately after to other double stars near them, the one appeared to be evidently blue, and the other of a silver colour. The blue star was in some instances on the right, and in others on the left. I saw also some single stars of a blue appearance, several of a bluish white, and others of an orange colour.

Mr. Herschel said to me with much modesty, that this discovery was not of very great merit, since it was easy to make it without recurring to large telescopes; acromatic ones with large object-glasses being sufficient to discover the coloured stars above mentioned.

The observations, however, of Mr. Herschel were at first much disputed, for it is much easier to deny than to examine. But they were soon confirmed, as they deserved to be, by the astronomers of Germany and Italy, and by M.M. Cassini [Jean Dominique], Méchain etc. of the observatory of Paris.

Mr. Herschel shewed me a pretty large work on the stars; which he designs to publish as soon as it is brought to a conclusion. He has confirmed what has been long since observed, that several stars distinctly marked in the ancient catalogues, and of which some are even laid down in the celestial Atlas of Flamsteed, have entirely

disappeared. It is thus probable, that there sometimes happen great revolutions and terrible catastrophes in several parts of the system of the universe; since, if the starswere suns, their extinction must have annihilated the organised beings who existed on the planets which they illuminated.

Jupiter, viewed with the telescope of twenty feet, appears much larger than the full moon. His parallel belts are very distinct, and his satellites are of a truly astonishing magnitude.

On directing the same telescope towards Saturn, we saw his ring in the most distinct manner, and also the shadow which it projected on the body of that immense and singular planet. Mr. Herschel shewed me the sky, and even several stars, in the interval between the moveable ring and the planet. By means of some luminous points which are remarked in the ring, he was enabled to discover that this solid circle has a rotation from west to east in the same manner with the other planets of our system.

The micrometer which Mr. Herschel uses is composed simply of two threads of silk, very fine, well stretched and parallel, which may be moved to a greater or shorter distance at pleasure. The instrument of parallel threads was known before, but this acute observator has perfected it, by finding an easy method of turning one thread over the other at pleasure; so that, on placing them in the telescope, he can take angles with the minutest precision.

The inventor of such large telescopes is far from having confined himself to those of twenty feet long. He was engaged in making the necessary preparations, to construct one of forty feet in length, and of a proportionable diameter.

Mr. Herschel’s intention, in constructing telescopes of this great size, is not so much to magnify the object, as to obtain, by the aid of mirrors of such a vast field, a more considerable quantity of light. This project is new and excellent. He told me, that he expected to encounter great difficulties in carrying to perfection a telescope of that great dimension and weight; but that he, at the same time, expected such great effects from it, that nothing should be capable of discouraging his progress.

I remained until daylight in that astonishing observatory, constantly occupied in travelling in the heavens, with a guide, whose boundless complaisance was never wearied by my ignorance, and the importunity of my questions. I passed about seven hours there, employed without intermission in observing the stars. It was impossible to think the time long, when spent in an employment of so profitable, and, with respect to me, curious information. That delightful night appeared no more than a dream to me, and seemed to last only a few instants; but the remembrance of it is indelible; and the grateful recollection of the kindness with which Mr. Herschel, and his interesting sister, condescended to receive me, will never be erased from my heart.

I left *Slough* (the name of the place where Mr. Herschel resides) about eight in the morning, to go to Kew [Kew Gardens Observatory].

We learn that Jupiter was observed with the "telescope of twenty feet". The planet, located in Aquarius, culminated about 0:45 am at an altitude of 27°. Since the 12-inch reflector was not suitable for visitors, the 18.7-inch is meant. However, it is not clear how Herschel could show the planet. There was no gallery and the seat offered space for only one person. Switching the observer must have been completed in less than a minute to keep the object in the field – a difficult task in the night. The last inconsistency concerns "Slough" – it was Datchet.

On 21 August (sweep 253), a remarkable globular cluster was discovered, NGC 7006 in Delphinus: "A pretty bright, irregularly round easily resolvable nebula; about 1' diameter. Hazy otherwise I suppose I might see the stars of it." The next night again was "too hazy to resolve it". On 15 October (sweep 290), Herschel wrote: "I missed the nebula of the 253rd sweep but having no notice of it, did not look for it, yet it is strange." The last trial was successful (16 October, sweep 294): "Very bright, round, much brighter in the middle, the brightness extending a good way, resolvable." Herschel later catalogued the 10.6 mag object as I 52. With a distance of 134,000 light-years, NGC 7006 is among the most remote globular clusters. It is astonishing that Herschel described the object of concentration class I as 'easily resolvable' (see Table 2-18 and

Figure 2-55).[452]

2.2.6. Fourth quarter – an expedition to the east and problems with M 20 and M 8

So far, all sweeps had been made in the south meridian. This would change on 29 September. Herschel wrote in *Journal No. 10A*: "The telescope turned towards the East." This was done by the 'round motion'. The Andromeda Nebula provided the motivation for this rotation, which had not yet been observed with the 20-ft.[453] Its altitude in the meridian was about 79° ($\delta = +40°$, PD = 50°); this was 6° more than previously practised. The instrument was unsafe at higher elevations. However, based on Caroline's (first) zone catalogue of Flamsteed stars, Herschel must have already been prepared for declinations up to +45° (PD 45°).

To observe M 31, Herschel decided to turn the telescope to the east (azimuth 90°), were M 31 stands 56° above the horizon in the autumn sky. He wrote: "I viewed the nebula in Andromeda with the great 20 feet reflector but full diameter made it impossible to see it to any advantage. I saw also the small one." Of course, the field of view (15') was far too small for the nebula, whose visually perceivable part extends over 45' × 20' (on photographic images, M 31 has even a size of 190' × 60'). The "small one" is M 32, first seen on 2 August 1783 with the 7-ft.

From 5 to 7 October, Herschel made five eastern sweeps (281–285). They are not listed in Caroline's *Sweep Records*, but can be found in *Sweeps No. 3* and *Journal No. 10A*. The unusual task brought many problems, because the sky is rotated 60° anti-clockwise relative to the meridian position. Thus, the standard calculations to determine positions were not applicable. William started sweep 281 at 7:50 pm; 10 minutes later, σ And passed the field of view at altitude 49°. He wrote: "Neither the degree nor the time of this sweep can be accurately determined but the observation of σ Andromedae settles it at least in a coarse way." The first eastern sweep lasted one hour.

Herschel immediately continued with sweep 282: "Higher than in the last sweep but at the same time the telescope turned more north." This was the perfect orientation for M 31. In the next two

hours, he saw several objects in and near the large nebula. Although his calculations for the coordinates are incorrect, all can be identified. First, he encountered "A streak of milky nebulosity, horizontal, or part of the 31st Nebula." This is NGC 206, a distinctive, elongated 14th mag super star cluster in M 31.[454] For the second object, we read: "A small nebula, it appears from this that Messier has it not." William catalogued the object as I 54, but Caroline noticed that it is M 32, the brightest companion of M 31, and added "is 32". Shortly after, at 9:00 pm, the central region of the Andromeda Nebula appeared for the first time in the 20-ft: "31st Nebula difficulty resolvable & milky mixed". Then Herschel saw "the new nebula like the 31st." This is the second companion, M 110 (NGC 205). He catalogued the 8.1 mag galaxy as 'large nebula' V 18, though it was Caroline's discovery of 27 August 1783.[455] Finally, a "part of 31st extending very far" passed the field.[456]

Sweep 283 on the 6th yielded five new objects. The first was "A much extended, resolvable patch; or bottom [lowest tube position] more affected than the rest, 6 or 7' long." This is NGC 7618 in Andromeda; the 13.0 mag galaxy was not catalogued by Herschel. It is just 1° west of the bright planetary nebula NGC 7662. That stunning object, known as the Blue Snowball, was discovered next: "A wonderful bright, round planetary pretty well defined disk, a little elliptical, perhaps 10 or 12" diameter." However, the blue colour was not noticed. Herschel catalogued the 8.3 mag planetary nebula as IV 18; it was sketched (Figure 2-63).[457]

One hour later, the outskirts of M 31 entered the field ("Much diffused nebulosity, or the 31st nebula already began."), then Herschel saw M 32. About two hours later, a large, elongated object appeared: "Near 15' long and near 2' broad, resolvable." This is the 9.9 mag edge-on galaxy NGC 891 in Andromeda (axis ratio 7). It was again seen on 17 & 24 October 1786 (sweeps 614 & 621) with the front-view. On the latter date, Herschel noted: "considerably bright, about 15' long and 3' broad. A black division in the middle in the direction of the length; at least 3 or 4' long." This is the first remark on the characteristic absorption lane for which the edge-on galaxy is so famous; the feature is seen in the sketch (Figure 2-63).[458]

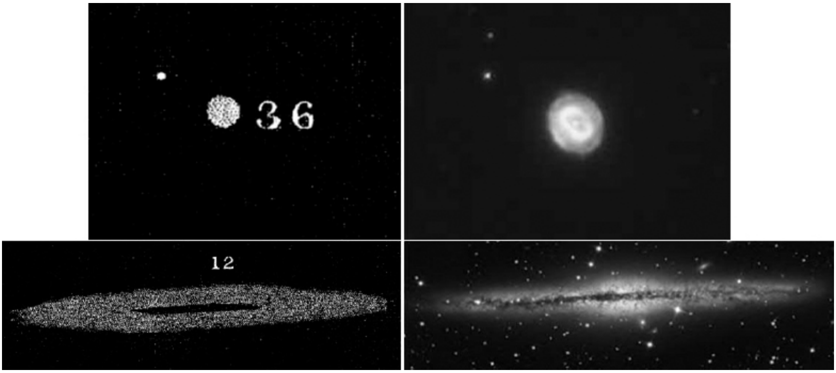


Figure 2-63: Above: The 8.3 mag planetary nebula NGC 7662 in Andromeda, known as the Blue Snowball, was discovered in the eastern sweep 283 on 6 October 1784. Below: The 9.9 mag edge-on galaxy NGC 891 in Andromeda, well-known for its stunning absorption lane. Herschel sketched the object on 24 October 1786.

Two more objects were found: NGC 946 and NGC 1003. The galaxy NGC 1003 (II 238) in Perseus was seen before NGC 946, although it has a larger AR. This is due to the rotated sky. NGC 946 (III 198) in Andromeda lies 2° northwest of the open cluster M 34, which was also observed. The last object in sweep 283 was Algol (β Per).[459] Herschel noted: "I was obliged to shorten the focus considerably after having adjusted it perfectly well upon Algol; I have found the same with other large stars."

Day	Sw	Object	H	Con	Type	V	Remarks
5	282	**NGC 206**	V 36	And	SC	14.0	super star cluster in M 31
5	282	M 32	I 54	And	Gx	8.1	again seen in sw 283
5	282	M 31	-	And	Gx	3.4	Andromeda Nebula, again seen in sw 283
5	282	NGC 205	V 18	And	Gx	8.1	M 110, found by Caroline
6	283	**NGC 7618**	-	And	Gx	13.0	
6	283	**NGC 7662**	IV 18	And	PN	8.3	Blue Snowball
6	283	**NGC 891**	V 19	And	Gx	9.9	edge-on
6	283	**NGC 1003**	II 238	Per	Gx	11.5	
6	283	**NGC 946**	III 198	And	Gx	13.2	not in *Zone Catalogue*
6	283	M 34	-	Per	OC	5.2	
7	285	**NGC 1160**	III 199	Per	Gx	12.8	pair
7	285	**NGC 1161**	II 239	Per	Gx	11.0	pair

Table 2-19: Non-stellar objects, seen in the eastern sweeps (chronological order); 'Day' in October 1784; bold = discovery.

On 7 October two sweeps were made. Nothing happened in the first

(284), but the second (285) brought a nice pair of galaxies in Perseus: NGC 1160/61 (III 199, II 239), separation 3.5'. Herschel wrote: “The first resolvable and pretty bright, the second very faint and irregular, both pretty small. No. 4 [240 ×] shewed them very plainly”.

Sweep 286 (8 October) began “in the Meridian again” – Herschel’s short intermezzo in the east was over. Later modifications of the telescope, allowing higher altitudes, made it unnecessary to turn it to the east again. Table 2-19 shows the observed non-stellar objects in this exceptional mission.

The bulk of observations in the second half of 1784 bear many more highlights. Here is a selection, based on interesting excerpts. Concerning brightness, extreme objects are the 6.3 mag open cluster NGC 6940 (VIII 25) in Vulpecula, found on 17 July (sweep 239). The night also brought a (true) planetary nebula: NGC 6894 (IV 13) in Cygnus, 12.3 mag bright. Herschel noted: “Pretty faint, exactly round, of equal light throughout. I believe it is resolvable, but am not certain.”[460] In sweep 245 on 7 August, Herschel discovered his smallest object, the planetary nebula NGC 6629 (II 204) in Sagittarius: “I suspected a pretty bright, small, stellar nebula.” The diameter of the 11.3 mag object (not in class IV) is only 16".[461] It is 1.5° north of M 28. Shortly after, the globular cluster NGC 6642 (II 205) was found, only 1° northwest of M 22; it was not resolved.

There is a spectacular case of a galaxy near a bright star. On 13 September (sweep 271), Herschel found NGC 404 (II 24), located only 6.8' northwest of the 2.1 mag star Mirach (β And).[462] He noted: “Pretty bright, notwithstanding the light of β Andromedae which is in the field with it, considerably large, round, brightest in the middle.” The 10.3 mag galaxy is known as Mirach’s Ghost. Another find was later sketched: NGC 925 (III 177), a 10.1 mag galaxy in Triangulum. See Figure 2-64 for both objects.

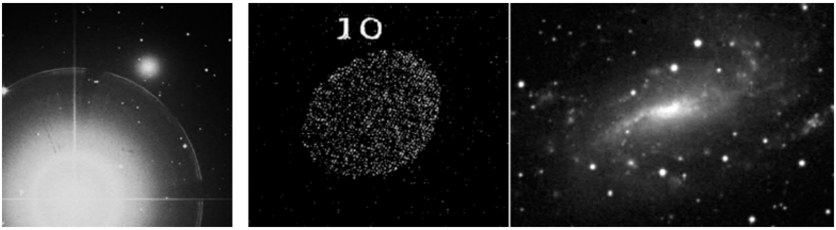


Figure 2-64: Two galaxies, discovered on 13 September 1784. Left: NGC 404 near Mirach (β And); right: NGC 925 in Triangulum (with sketch).

On 7 August (sweep 245), Herschel found the 8.4 mag globular cluster NGC 6717 (III 143) in Sagittarius (Figure 2-65).[463] It lies near the stars ν^1 and ν^2 Sgr at -23° declination. Herschel wrote: “Two or three minutes south of 35 [ν^2] Sagittarii are three very small stars which I suspect to contain nebulosity; but it is probably a deception circumstances are not favourable enough to determine it.” The 5.0 mag star ν^2 Sgr is only 1.8' north of the cluster; ν^1 (4.8 mag), located 14' east, was out of the field and not seen. The conspicuous pair ν^1 / ν^2 Sgr was already known to Herschel from Ferguson’s list of ‘Cloudy stars’. Here the author of the popular astronomy book refers to Ptolemy; the duo is known as Ptolemy’s Eye. Caroline later noted: “35 Sagittarii [ν^2 Sgr] is called nebulosæ by Flamsteed.” Appeared the combination of star and globular cluster appeared nebulous in Flamsteed’s 7-ft refractor? This is unlikely, because the Astronomer Royal saw both ν^1 and ν^2 Sgr as ‘Nebulosæ’ on 8 June 1691.

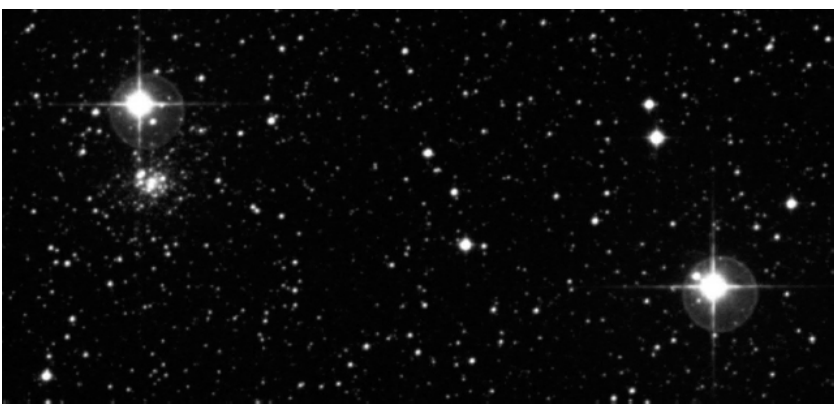


Figure 2-65: The 8.4 mag globular cluster NGC 6717 is just 1.8' south of ν^2 Sgr, making a nice pair with ν^1 Sgr, 14' west, known as Ptolemy's Eye. Herschel found the tiny cluster on 7 August 1784.

On 16 September (sweep 275), Herschel discovered the planetary nebula IV 16 in Delphinus: "Perfectly round, pretty bright, pretty well defined, about 3' in diameter." It was seen again in the following night (sweep 276): "As described last night. Between 2 stars of unequal brightness, that to the north being the brightest, resolved, and the night being very fine shows it less defined on the edges that in 275 sweep, so that I do not doubt but it consists of very much compressed stars." The 11.1 mag object, known as the Blue Flash Nebula, was catalogued by Dreyer as NGC 6905. For remarkable planetary nebulae, Herschel created finder charts, allowing a simple 'star-hopping' (Figure 2-66).[464]

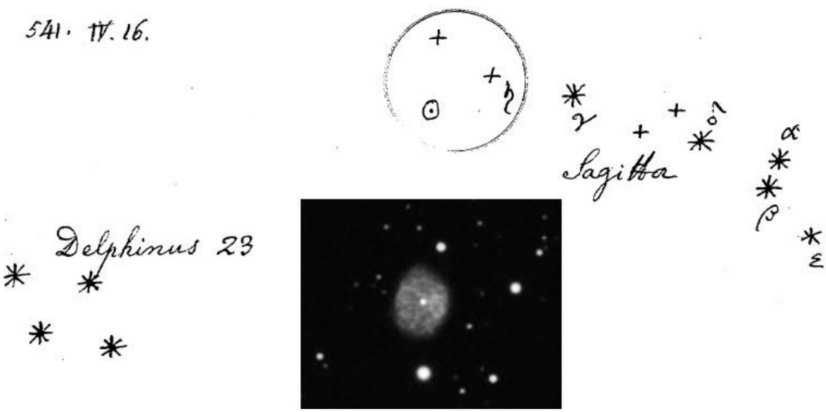


Figure 2-66: The 'star-hopping' trail to the planetary nebula IV 16 (GN 541, NGC 6905) in Delphinus starts in Sagitta; the number 23 refers to the chart in the *Atlas Coelestis*. The circle is the finder view.

A peculiar connection of a nebula and a star appeared on 16 October in sweep 296: "A pretty large star, about 9 m, surrounded by milky nebulosity not circular; but an irregular ellipsis." The object in Monoceros was catalogued by Herschel as 'planetary nebula' IV 19. The 'central star' has a brightness of 10.6 mag. Actually, this is a reflection nebula, listed by Dreyer as NGC 2170 (see Figure 2-67).

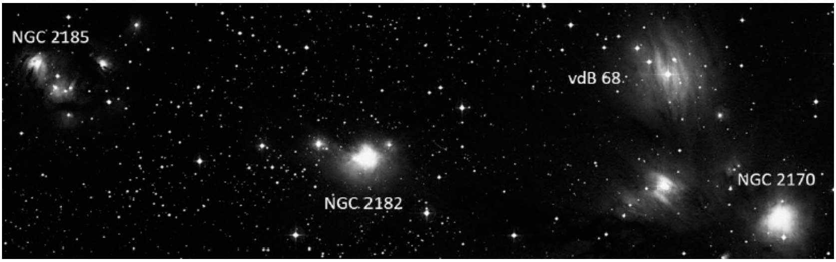


Figure 2-67: In 1784 and 1786, Herschel discovered a quartet of reflection nebulae about 1.5° east of γ Mon; the distance between NGC 2170 and NGC 2185 is 1°.

Immediately after, another reflection nebula was found 1° east; this is NGC 2185 (IV 20). Herschel's description reads: "5 or 6 stars pretty strongly affected with milky nebulosity, which takes up a place of 7 to 8' in extent, irregularly formed. The stars are not connected with it, though I suspected it last night." Both objects were seen again in the next night (sweep 529). They are members of a quartet of conspicuous reflection nebulae in the eastern part of Monoceros (Figure 2-26, Table 2-26).

Object	H	Date	Sw	V (star)	Other observations (sweeps)
NGC 2170	IV 19	16 Oct. 1784	296	10.6	23 & 24 Feb. 1786 (528, 529)
NGC 2185	IV 20	16 Oct. 1784	296	11.6	23 & 24 Feb. 1786 (528, 529)
NGC 2182	IV 38	24 Feb. 1786	529	9.3	28 Nov. 1786 (640)
vdB 68	IV 44	28 Nov. 1786	640	9.3	

Table 2-20: Reflection nebulae, discovered by Herschel in a region, covering about 1° and located about 1.5° east of γ Mon; the star is not involved (Figure 2-67).[465]

A curious case appeared on 6 September in sweep 258. At 8:40 pm, Herschel saw a red star in the neck of Cygnus: "7-8 m, a beautiful garnet star." Caroline listed it as 'unknown star' U^{220}. Four minutes earlier, a Flamsteed star was observed, called '17 (ε) Cygni' and used as reference star in the sweep. In the *British Catalogue* it is listed as the 17th of the constellation Cygnus, named 'ε' with a magnitude 5 (Figure 2-68). Moreover, a star 'ε' appears both on the Harris map and in the *Atlas Coelestis*. According to Flamsteed, Caroline had added the number '17' to 'ε Cygni' in the atlas. The place of the nearby 'garnet star' U^{220} was now marked '*' on the

chart. What is the curiosity? The designation ‘ε Cygni’ is due to Johann Bayer; the star first appears in his *Uranometria* of 1603. In July 1686, Gottfried Kirch noticed that Bayer’s star was missing; he first saw it on 19 October. Further observations yielded a variability over 405 days. Due to modern measurements the star shows an immense brightness change of 3.3 to 14.3 mag. Comparing the positions of Flamsteed’s ’17 Cygni’ and Kirch’s variable star ‘ε Cygni’, there is a deviation of more than 1°.[466] An analysis shows that the stars are not identical! When Flamsteed observed the region, the variable star was too faint for his 7-ft refractor. He measured a 5.0 mag star, 1.2° northwest, which was catalogued as ‘17 Cygni’. Not knowing about the nearby variable star, he misidentified his ‘17’ as Bayer’s ‘ε Cygni’. The Herschels were apparently unaware of the fact that the ‘garnet star’ U220 was identical with Kirch’s variable – but they should have known better, as they had use of references that made it clear! Near ‘ε Cygni’ the Harris map shows an interesting entry: ‘Nova 1686’, which refers to Kirch’s observation on the appearance of the star. Moreover, Ferguson’s *Astronomy* also mentions the star (see section 1.6.2). Obviously, both Bayer and Herschel were luckier to view the variable at a greater brightness than Flamsteed. Nowadays, it is called ε Cyg (it bears no Flamsteed number), whereas 17 Cyg is a 5.0 mag star 1.2° northwest.[467]

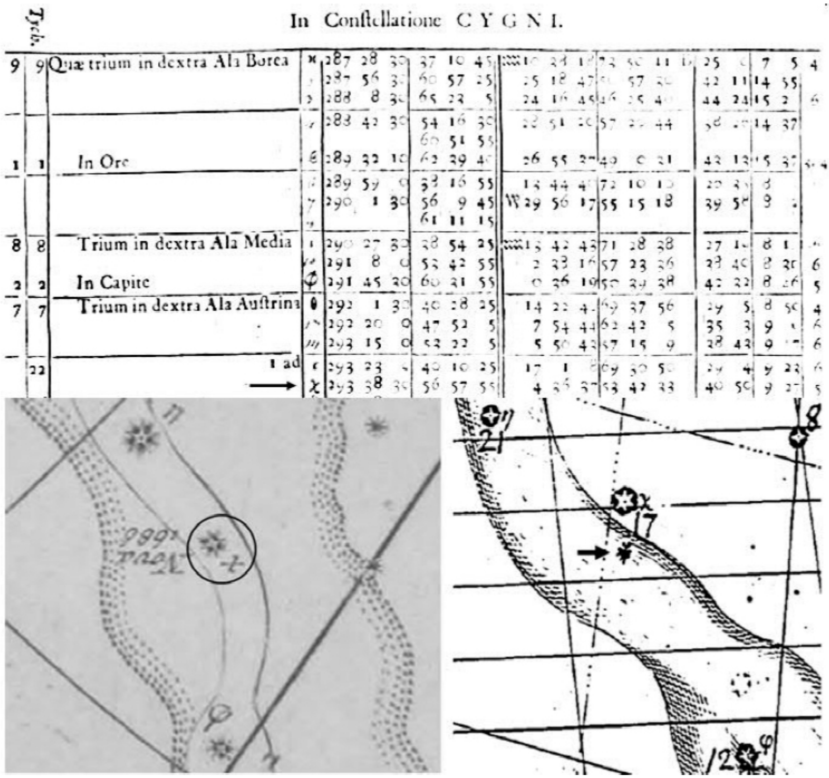


Figure 2-68: The curious case of the ‘garnet star’ ε Cyg. Flamsteed uses this designation in the *British Catalogue* for the 17th star of Cygnus (above, last entry). Both the Harris map (bottom left) and the *Atlas Coelestis* show a star ‘ε’. On the latter chart, Caroline added the number ‘17’ for it and a ‘*’ symbol (arrow) for the discovered red star. Note the label ‘Nova 1686’.

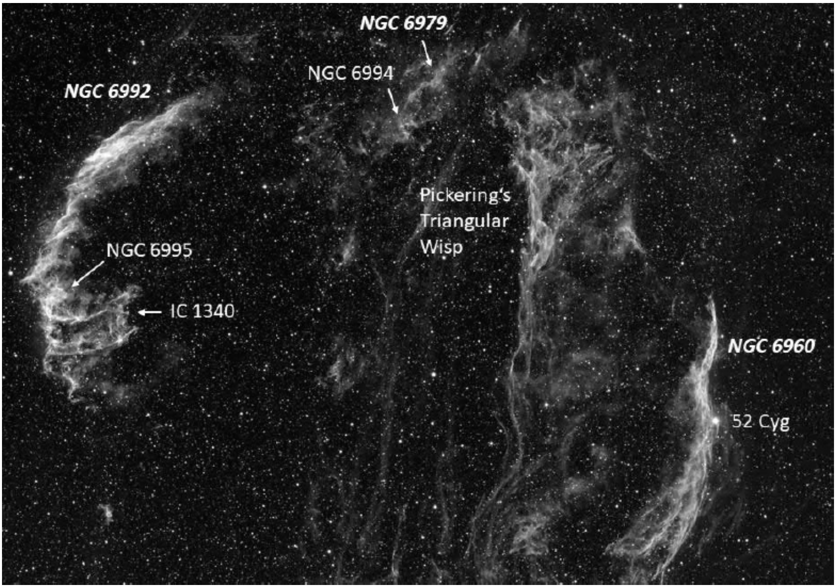


Figure 2-69: The Veil Nebula complex in Cygnus and Herschel's discoveries (italics) on 6 & 7 September 1784. Other parts were found later by different astronomers (see text).

Another star in Cygnus played a role about an hour later that night: 52 Cyg (4.2 mag). The story is about the discovery of the famous Veil Nebula on 6 and 7 September 1784 (sweeps 258 and 259). There are four recorded observations in the two nights, designated [1] to [4]. On 6 September [1], a large nebula crossed the field of view at 9:30 pm, together with a 4.2 mag star (Herschel's k Cygni). On 7 September (sweep 259), the object was seen again [2]. Shortly after two other nebulae were found [3, 4].

[1] Extremely faint, above ¾ degrees long and 6, 8 or 10' broad. The whitishness intirely of the milky kind, brighter in 3 or 4 places than in the rest. The position of the Ray or extent is from np to sf making an angle of 30 or 40 degrees with the meridian. The stars of the Galaxy [Milky Way] are scattered over it in the same manner as over the rest of the heavens. The time & number is taken in the brightest part of the nebula. It follows ε Cygni 11.5 [minutes] in time & is 2° 9' more south. The ray is faint enough to have been overlooked had it not been for the brighter places in it.

[2] Extended from one number to the other. Pretty bright, taking in k Cygni [52 Cyg] in its extent. The milky ray is convex towards the following side in that part which lies north of k, pretty compact and equally bright, on the southern side of k it is less bright and at last loses itself with some extension, perhaps in two branches, but it is not bright enough that I may determine this circumstance with certainty. The breadth of the northern branch is less defined.

[3] Faint, small, crookedly extended resolvable. It follows k Cygni 5.6 [minutes] in time & is 1° 15' more north.

[4] Branching nebulosity of the extent of the number that is 48' in polar distance, and in AR reaches thro' 5 or 6 fields that is near 1½ degrees. The following part of it is divided into several streams and windings which after separating meet each other again towards the south. It follows k Cygni 11.4 [minutes] in time & is 48' more north.

[1] and [4] describe the extended eastern part of the Veil Nebula, catalogued as V 14 = NGC 6992. [2] concerns the large western part: V 15 = NGC 6960, involving 52 Cyg. [3] relates to a small patch in the north: II 206 = NGC 6979, 1.7° northeast of the star. The large nebulae are mentioned in Herschel's first catalogue of 1786.[468] However, there he speaks about three objects, referring to the observations [2], [1] and [4]. Obviously, he had not noticed that the latter two are identical (Figure 2-69). The "branching nebulosity" NGC 6992 (V 14) was seen again in sweep 272 (15 September). It is figured in Herschel's publication of 1811 as an example "Of extensive diffused Nebulosity" (Figure 2-70).[469] He wrote that it is "a phenomenon that hitherto has not much been noticed, and can indeed only be perceived by instruments that collect a great quantity of light."

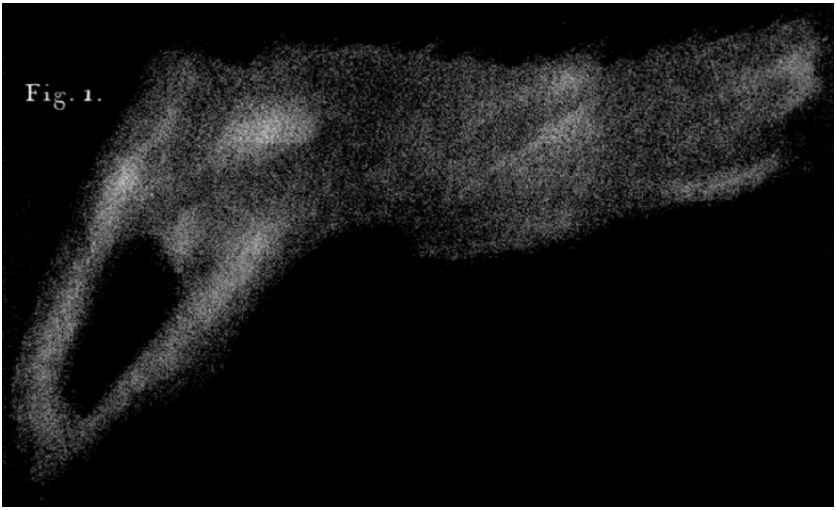


Figure 2-70: NGC 6992, the eastern part of the Veil Nebula in Cygnus, drawn by Herschel on 6 September 1784; it is an example of an ‘extensive diffused nebulosity’.

It is astonishing that Herschel noticed such faint, large nebulae in his small field of view – not being prepared for it. Visually, the contrast between the nebulous mass and the background sky is low and there are no significant edges. But he was an experienced observer, knowing all tricks. The key issue is the sky motion: the nebulous masses passed through the field of view. In case of a moving object, the eye becomes very sensible to small contrast changes, regardless if the motion is active (sky) or passive (tube). This latter is exploited in the technique of ‘field sweeping’. To view a faint object, a slight (perhaps periodical) motion of the tube is often sufficient. Due to the position change in the field of view the object jumps into perception. Without tracking, it naturally moves through the field. By this method, Herschel was able to discover very faint nebulae.[470]

NGC 6960 was seen again in sweep 615 (18 October 1786), but now in the front-view mode: “The nebulosity extends as far as this to the south, and I believe much farther. It divides itself in 2 or 3 branches; but they are too faint to be pursued.” Herschel’s short description, given in the first catalogue for V 15, ends with “By the Front-view mode near 2 degrees long.” This is irritating, because

the later sweep is not mentioned.[471]

Three other NGC/IC objects are in the Veil Nebula complex. In 1825, John added NGC 6995, south of NGC 6992.[472] Truman Safford found a part in 1866, catalogued as IC 1340.[473] Finally, Lawrence Parsons discovered NGC 6974 with the 72-inch in 1873.[474] Moreover, there is Pickering's Triangular Wisp, a faint nebulous complex between NGC 6979 and NGC 6960. It was found on a plate by Williamina Fleming, taken in 1904 with the 24-inch refractor at Arequipa Observatory (Peru).[475] The Veil Nebula covers an area of 2° and is the remnant of a supernova that exploded about 7000 years ago. The distance is 1470 light-years and the linear diameter is about 110 light-years.

Another large emission nebula was found on 9 December (sweep 333). Herschel wrote: "Large, almost round, 6 or 7' diameter, intirely milky, a pretty large star not far from the center; a very curious appearance." This is NGC 2467 in Puppis, located 3° southeast of the open cluster M 93; it was catalogued as 'planetary nebula' IV 22. This is Herschel's emission nebula with the lowest declination (-26°).

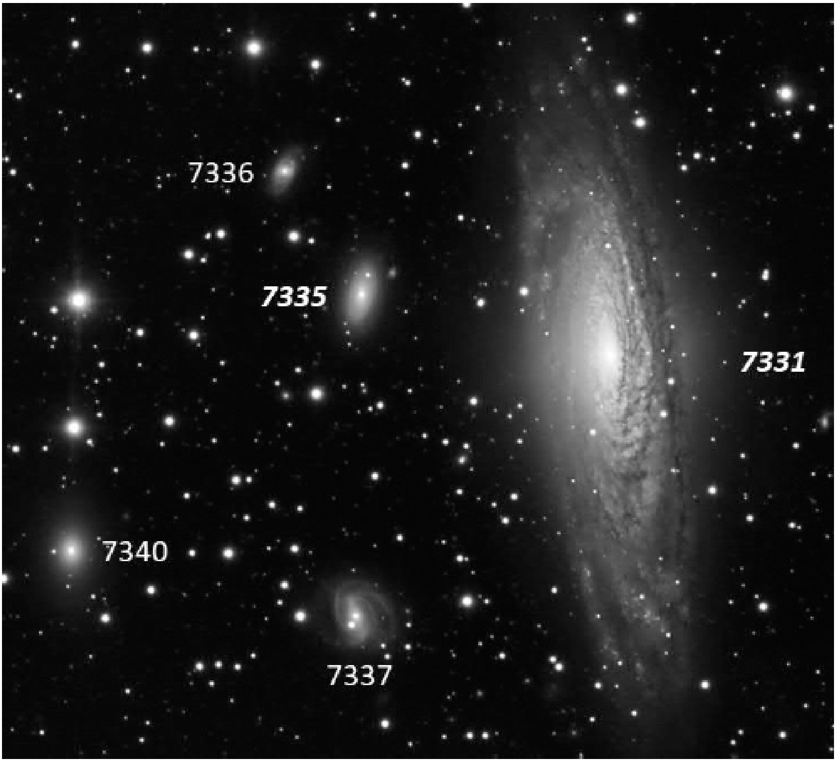


Figure 2-71: The 9.5 mag galaxy NGC 7331 in Pegasus and its companions; Herschel's found NGC 7331 on 6 September 1784 and, seven days later, NGC 7335 (13.3 mag).

There were also some prominent galaxies. Shortly after NGC 6960 was seen in sweep 258 (6 September), the telescope was 'left off'. Herschel started a new pass, when Pegasus came into view. Although the Moon was pretty bright now and the sky became hazy and cloudy, he discovered the 9.5 mag edge-on galaxy NGC 7331 (I 53): "Extended, a little brighter in the middle, pretty bright, considerably large." Under better conditions, Herschel would have noticed Stephan's Quintet, the famous galaxy group, only 30' southwest of NGC 7331. The elongated galaxy was again seen much better on the 13th in sweep 269: "very bright, considerably large, much brighter middle, resolvable, much extended". Alas, the quintet was now just below the sweep. However, a companion of NGC 7331, 3.5' east, was found: the 13.3 mag galaxy NGC 7335 (III 166); see Figure 2-71.[476]

On 19 September (sweep 299) the bright barred spiral NGC 7479 (I 55) in Pegasus was found. However, the spiral structure, celebrated later by Lord Rosse, was not recognized (Figure 2-72).[477] Herschel wrote: “Much extended, resolvable, faint, near 3' in length and about 1' in breadth. I see 2 or 3 stars in it; but they do not seem to belong to it.” Another bright Pegasus galaxy was found on 8 October (sweep 286), when Herschel was back in the meridian after his successful expedition to the eastern sky. This is NGC 7814 (II 240).

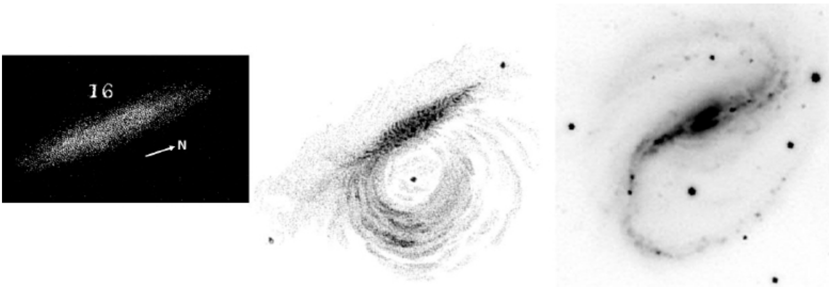


Figure 2-72: The 10.9 mag barred spiral galaxy NGC 7479 in Pegasus, discovered by 19 September 1784 (left). Lord Rosse detected the spiral structure in 1849 and made a fine drawing (middle); right: modern image.

The night of 17 November (sweep 320) brought a doubtful object in Pegasus, not catalogued by Herschel: “Suspected but 240 shewed 2 stars, and left it doubtful whether they contained nebulosity between them or not; rather against.” This is the 13.0 mag galaxy NGC 7810. John observed the object on 11 and 12 September 1828; it was catalogued as h 2296, referring to ‘H.MS.’, meaning ‘Herschel manuscript’. However, he did not know about the nebula from the sweep records (which bear many more uncatalogued cases), but from Caroline’s *Zone Catalogue*, prepared for his observations. There it is listed in the PD zone 78° as ‘a suspected one’. Later the object was added by Dreyer in the *Scientific Papers* as III 984.

Another interesting find was made in Eridanus: the large face-on galaxy NGC 1232 (II 258). It was seen in sweep 303 on the 20th; with 3.1° the breadth was large (especially for the low elevation of 16°).[478] In that sweep, another spectacular object was discovered: the extended 9.1 mag galaxy NGC 247, located at -23° declination

in Cetus. Herschel wrote: “A streak of light, the first and last No. [PD index] was the brightest part of it, which was pretty bright, the other numbers the extremes. The extension nearly in the meridian (I believe a little from the sp to nf – by memory) about 3 or 4' broad.” The object, catalogued as ‘large nebula’ V 20, was never seen again.

Herschel discovered 21 pairs and three trios of galaxies. Most ensembles were found in a single field of view. Here is a selection of the best cases. On 11 September (sweep 266), Herschel wrote: “Extremely faint, 5 or 6' diameter, 3 or 4 stars in it; but they seem to have no connection with it.” The object in Andromeda was catalogued as ‘large nebula’ V 16. Actually, this is a group of galaxies, consisting of NGC 67, 67A, 68, 69, 72A, 70, 71 and 72 in a range of 12.9 to 14.7 mag (the brightest is NGC 68). The eight members are confined in a circle of only 5' diameter. The compact ensemble, mixed with some 14th mag stars, might give the impression of a ‘large nebula’. The following night (sweep 268) was special: Herschel found four pairs and two trios. The first is NGC 379/80/83 (II 215-17) in Pisces.[479] The trio belongs to the NGC 383 chain: eight galaxies are lined-up north-south over 12'. Herschel wrote: “Three faint, very small, round, all in a row in the meridian, nearly of equal size the distance between the two south is about double that of the other.” He did not recognize that NGC 383 (the lowest of the three) is a very close double galaxy; the companion NGC 382 is only 33" south.[480] Then, about 1° northwest of the trio, he saw NGC 407/10 (II 217/19), 5' apart. Another 2.5° east, Herschel had entered the field of the NGC 507 galaxy group. He discovered five members of 20, lying within a circle of only 30'. NGC 495/96/99 (III 156-58) was seen as a trio (“three, extremely small, faint, forming a triangle”) and NGC 507/08 (III 159/60) as a close pair (“two, extremely faint, unequal, both small”), the separation is 1.5'. Both galaxy groups are shown in Figure 2-73.

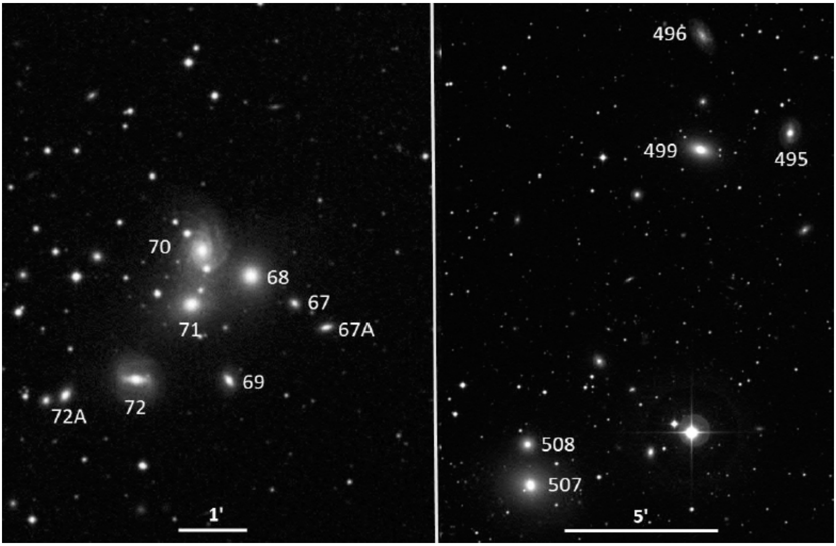


Figure 2-73: Left: The compact galaxy group around NGC 68 in Andromeda, seen as a 'large nebula' on 11 September 1784. Right: On 12 September 1784, Herschel discovered five members of the NGC 507 group in Pisces.

In Triangulum, Herschel encountered two more pairs. The first is NGC 736/50 (II 221/22), not seen in a single view (distance 15'). NGC 750 itself is a very close double; the companion (NGC 751) of similar size and brightness is only 20" away. This is a contact pair of giant elliptical galaxies, forming a dumbbell.481 Herschel only saw a "much extended" object, though he had split even closer double stars – of course, nebulae are different.482 The last pair of the night was NGC 1060/61 (III 162/63) in Triangulum (separation 8').

An interesting case appeared in sweep 277 (18 September). Herschel discovered the galaxy pair NGC 7769/71 (II 230/31) in Pegasus. The second galaxy is described as: "Extended, pretty large, faint, resolvable, the extension in the direction of the parallel towards the south preceding part seems to be a very small nebula; within the nebulosity of the large one; but it may be only a small star." Actually, he saw a faint third component: NGC 7770, about 1' southwest of NGC 7771. The object was not catalogued.483

The night of 19 September (sweep 278) brought a remarkable pair

of edge-on galaxies in Pegasus: NGC 7332/39 (II 233/34). They are 5' apart and show perpendicular orientations.[484] However, Herschel saw them in different fields and noted: “Extended, pretty bright, easily resolvable. I can distinguish one or two stars.” and “Extended, faint, resolvable, the direction of the extent different from that of the foregoing.” In sweep 302 we read for the galaxies (again not seen in one field): “direction nearly in the meridian” and “direction almost at rectangles to the former”. In sweep 319 (16 November), the pair was eventually seen in a single field (“both much elongated in different directions”). A similar case of two perpendicular edge-on galaxies is NGC 5560/66 (II 579/I 144) in Virgo, discovered on 30 April 1786. Both pairs are shown in Figure 2-74.

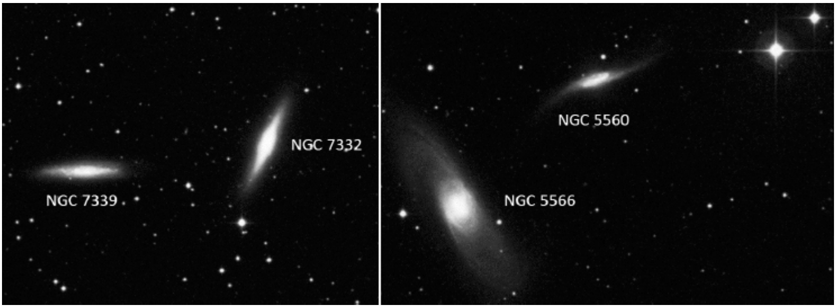


Figure 2-74: Two pairs of edge-on galaxies with different orientations. Left: NGC 7332/39 in Pegasus with 11.1 and 12.2. mag, distance 5' (16 November 1784). Right: NGC 5560/66 in Virgo with 12.4 and 10.6 mag, distance 5.3' (29 April 1786).

On the 20th, three pairs were discovered in Pisces, Aquarius and Eridanus. The last, seen in sweep 280, is pretty close (2'): NGC 1321/20 (III 196/97) in Eridanus. Herschel noted: “Two, extremely faint, 240 verified them. With No. 1 [157 ×] I had but a very distant suspicion of them.” This night brought another interesting object in that constellation: the galaxy NGC 1253. Herschel wrote: “A small star with a nebulous brush following (with 240); I am sure with No. 1 I should have overlooked it. The brush was faint and about 1½ or 2' long. A star on each side which I viewed were free from that brush tough I drew them in the same part of the field.” Undecided how to treat the strange object, he put it in the 4th class as IV 17 (see Table 2-26 and Figure 2-92).

On 12 November (sweep 313), another trio was discovered: NGC 7778/79/82 (III 231-33) in Pisces. They build a 12' long galaxy chain. The first two members were seen in one field. In the night of 13 December (sweep 338), Herschel saw two galaxy pairs in Pisces. The first is NGC 470/74 (III 250/51): “Two, very small, very faint, round, almost stellar 4 or 5' from each other in a parallel; the time is that of the first I believe but am not sure as I did not perceive there were two till one was taken.” Actually, it is a trio. On 8 October 1785 (sweep 462), Herschel saw the two again – and found the third member: NGC 467 (I 108), 11' southwest of NGC 470. The second pair, seen on 13 December, was NGC 741/42 (II 271/72). The galaxies are only 50" apart (see Figure 2-101 and Table 2-28). Herschel’s description implies one object: “Considerably small, just following a pretty bright star; of an unequal light and scatteredly extended.” The size difference of the round objects is also remarkable: while NGC 741 has a diameter of 3', NGC 742 measures only 0.3' (the high surface brightness object is his smallest galaxy). The “pretty bright star” is of 11th mag. In sweep 464 (25 October 1785), he saw two objects: “Faint, I take it to be two very near each other, 240 strengthened the suspicion.” Curiously, in sweep 607 (30 September 1786) he again describes only one nebula: “A sort of nucleus, irregularly formed.” This might be caused by different atmospheric conditions (seeing, transparency).

On 20 December (sweep 349), the 11.9 mag edge-on galaxy NGC 3044 (III 254) in Sextans was found. The extremely flat object shows an axis ratio of 7.[485] Herschel wrote: “Very faint, about 5' long but extremely narrow less than ¼' broad.” He made a sketch (Figure 2-75). In the same sweep, Herschel discovered the pair NGC 4073/77 in Virgo. The components are 7' apart. Though fitting into the field of view, he made two separate entries, II 277 and III 258, but noted for each object “goes in the same field conveniently”.

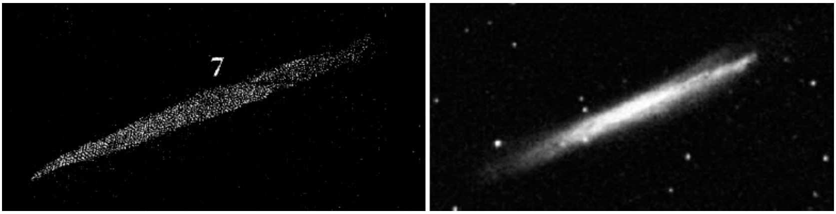


Figure 2-75: The extremely flat 11.9 mag galaxy NGC 3044 in

Sextans, found on 30 December 1784, measures 4.7' × 0.7'.

There are cases of double or triple nebulae where the members show different types. The first concerns a pair, located in Triangulum, found on 11 September (sweep 266). Herschel wrote: "18' long, and about 8 or 10' broad; or near 12' in the middle, faint, brighter and broadest in the middle, to the south of it is a small round nebula brightest in the middle, very faint the ends lose themselves nearly in the meridian or from a little south preceding to north following, there is also a roundish place which seems brighter than the rest and is detached enough to form a different nebula but may perhaps belong to the same." He catalogued the objects as 'large nebula' V 17 and 'very faint nebula' III 150. In the following night (sweep 268), the remarkable duo was observed again: "The top or northern part of the great nebula. The bottom or south part extends much farther down than what is given in the former observation it is also very much broader, I suppose no less than half a degree; but it is shaded away so imperceptibility that I could only see the sides by moving the telescope sideways, and thus comparing the nebula with the pure ground that surrounds it." Now Herschel measured "the PD of the small nebula following the great one". Both observations are mentioned in his publication of 1785, as the fourth example of a 'milky ray'.[486]

Even in a third observation, made on 11 January 1787 (sweep 680), the identity of the large nebula was not clarified. Interesting is Caroline's memorandum ('Mem') of an observation, made 20 minutes later, right after α Tri was measured: "Looked for the 33rd of Connoiss. des temps, but it is not in the place." This was Herschel's first attempt to view M 33 with the 18.7-inch. Actually, he had seen the Triangulum Nebula in all three sweeps! The missing identification is curious; Caroline's dot and label '33' are placed correctly in the *Atlas Coelestis*. Only in the *Zone Catalogue* do we find a remark for V 17 (added later): "is Messiers 33rd?"[487] The companion III 150 is actually a 12th mag HII-region in M 33, about 12' northeast of the centre. It was catalogued by Dreyer as NGC 604, who also correctly identified V 17 with Messier's nebula (actually discovered by Hodierna in 1654).

In Herschel's first observation of M 33 on 2 August 1783 with the 7-

ft, he speaks about a cluster with nebulosity (Messier never mentioned a ‘cluster’), writing: “Scattered stars with a whitishness too faint to be resolved by this telescope.” This was partly confirmed on the 24th: “A suspicion of extensively small stars.” In the sweeps (not knowing he was seeing M 33) it is not spoken of as a ‘cluster’. However, when Herschel returned to his ‘former’ object in later years, the term ‘cluster’ appears again. There were five observations with various reflectors. On 28 October 1794, we read: “with 120 it seems to be composed of stars and I think I see several of them” (7-ft). This was confirmed on 28 December 1799 (10-ft). On 9 December 1805, the famous ‘X-foot’ was used:[488] “A few of the stars of this cluster are visible in the center.” This exceptional reflector was again pointed at M 33 on 25 September 1810: “The condensation is very gradual towards the middle. The cluster is not regularly round and some nebulosity remains with all the 4 powers of 71, 108, 171, and 220. It is too faint for the high magnifiers. It certainly is insulated with respect to the smallest points imaginable. It cannot be called globular, but is certainly solid on account of the condensation which is visible.”[489] Finally, we read on 4 October 1810: “It is a very large cluster, nebulous in this instrument [X-foot] & power 71.” Obviously, the 20-ft was different – and the knowledge of the object’s identity.

A similar case happened on 16 November (sweep 318), when Herschel inspected an object in Leo: “Considerably bright, considerably large, a small bright spot in the middle at first sight appeared very much extended; but by careful attention it appears to consist of two, the north following of which is less bright than the south following, tho’ nearly of the same size and shape with the former it has also a british [brightish] spot in the middle, but not nearly so brilliant as the other. Distance of the center about a minute.” The compound was catalogued as I 56/57. The main object is the 9th mag galaxy NGC 2903 (the “small bright spot in the middle” is the nucleus); the component is NGC 2905, a distinctive HII-region of only 6" diameter and about 15th mag.[490]

On 9 September (sweep 261), Herschel found a ‘cluster’ in Vulpecula: “A cluster of coarsely scattered stars, not very rich.” The object was catalogued as VIII 20. In the next night (sweep 263), he saw “A cluster of coarsely scattered stars”, placed only 15' southeast

and catalogued as VIII 22. Curiously, Dreyer reversed the AR order and lists NGC 6882 = VIII 22 and NGC 6885 = VIII 20. However, there is no open cluster in the area, but only a few star groups. One of them, 6' northwest of 20 Vul (which is not mentioned), may fit to VIII 20. It is likely that Herschel saw this pattern twice and the two entries are identical.

On 12 September (sweep 268), Herschel discovered the 12th mag galaxy NGC 421 (III 155) in Pisces. He wrote: “Two extremely faint, and very small the following the largest.” The preceding companion was catalogued as III 154; but this is only a 12.9 mag star (NGC 420), 10' southwest. The night brought another galaxy in Pisces: NGC 296 (II 214). Herschel wrote: “Faint, extended, just preceding a bright star, appears almost like a brush ishuing from the star, but does not join it by a good deal.” Actually, the 12.6 mag galaxy has an asymmetrical shape (see Table 2-26 and Figure 2-92). NGC 1240 (III 164) in Aries was remarkable too: “Suspected, 240 left No doubt extremely faint and very small, most probably 2 close stars between 2 stars.” However, Herschel was sceptical about the vision: “Looked at the Specula and found them free from dew.” Actually, there is an ensemble of four faint stars at the position.

The case of NGC 552/553 (III 172/173) in Pisces is similar. The ‘nebulae’ were found on 13 September in sweep 271 and described as “Two very small, stellar; but a little doubtful.” This is a pair of 14th mag stars, 1.3' apart: the only case where the stars of a pair were catalogued separately (see Table 5-17). In this sweep, many ‘stellar nebulae’ were found: “I suppose this part of the heavens to contain hundreds of stellar nebulae, it should be examined with a higher power.”

A Messier object is involved in the next case. On 12 July (sweep 236), Herschel encountered a triple nebula in Sagittarius: “Three nebulae, but they seem to join faintly together forming a kind of triangle; in the middle which is less nebulous, or perhaps free from nebulosity, is a double star of the 2nd or 3rd class. As I intended to revisit this place very soon I passed on, but think more very faint nebulosities are following.” He catalogued the trio as ‘large nebulae’ V 10–12 and the central double star as N6.[491] In sweep 566 (26 May 1786) the region in Sagittarius was looked-up again, now

finding “A double star with extensive nebulosity, of different intensity; about the double star is a black opening, resembling the nebula in Orion on a small scale.” Herschel now catalogued the double star as N40 and the surrounding nebulosity as ‘planetary nebula’ IV 41. A minute later, he found “A very coarsely scattered cluster of stars. The 20^{th} of the temps.” After another minute, he saw “A rich cluster of large stars. The 21^{st} of the Connoiss. des temps.” Obviously, felt he had seen M 20 and M 21. Messier found both on 5 June 1764; his positions fit well: M 21 is 40' northeast of M 20. Both objects are correctly plotted by Caroline in the *Atlas Coelestis*.

Herschel had seen them already on 2 August 1783 with the small 20-ft as “two parcels of stars”. Did he expect a nebula for M 20? Not really. Messier’s description reads: “Star cluster, a bit above the Ecliptic, between the bow of Sagittarius and the right foot of Ophiuchus.” However, for M 21 the French astronomer noted: “Star cluster, near the foregoing; the star nearest to both clusters is the eleventh of Sagittarius, seventh magnitude, after Flamsteed. The stars of both clusters are of eighth and ninth magnitude, surrounded by nebulosity.”[492] Despite the mention of a nebulosity, Herschel was satisfied. He knew that Messier often believed he had seen ‘nebulosity’ in star clusters, which is typical for small telescopes. Today we associate the Trifid Nebula with M 20, though there are some stars involved. The name was coined by John, writing on 1 June 1828: “very large, trifid, three nebulae with a vacuity in the midst”. On 24 May 1835, he made a drawing at the Cape (Figure 2-76).[493]

To summarize the situation: in sweep 236, Herschel saw the Trifid Nebula and interpreted it as three separate objects. Misled by Messier, he could not identify the nebula with the ‘star cluster’ M 20. Moreover, his position is about ½° further south. In sweep 566, Herschel again saw the Trifid Nebula and determined a correct position. Due to the error in the earlier sweep, he did not identify the observations as being of the same object, although there are clear indications (structure, central double star). Then he saw a “very coarsely scattered cluster of stars”, located between the Trifid Nebula and M 21, which he identified with Messier’s ‘cluster’ M 20. Next, Herschel correctly saw M 21. So we have V 10 = V 11 = V

12 = IV 41 = M 20 and N6 = N40.

The other, even more complex story, concerns the Lagoon Nebula M 8 in Sagittarius, located 1.5° south of M 20 (Figure 2-77).494 Herschel had observed the bright nebula on 24 August 1780 with the 6.2-inch reflector, not knowing that he had seen the bright Messier object.

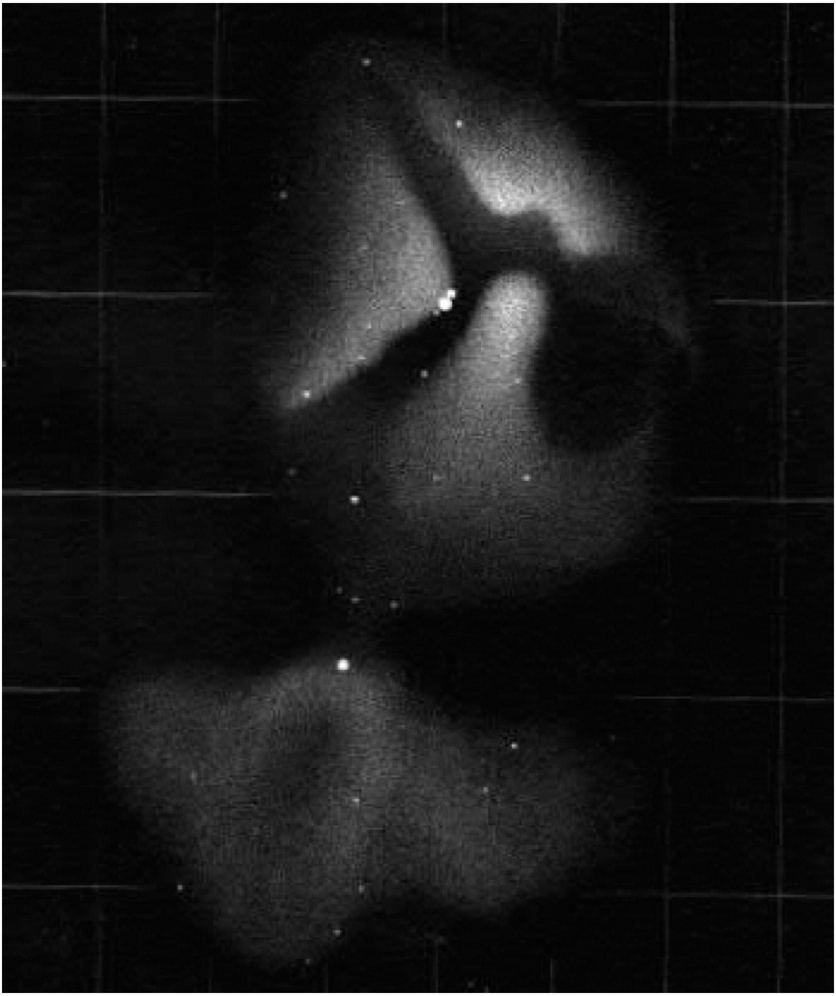


Figure 2-76: John Herschel's spectacular drawing of the Trifid Nebula M 20 in Sagittarius, made on 24 May 1835 using the 18¼-in reflector at Feldhausen (here reproduced as negative, south is up).

It shows the three nebulous parts (coining the popular name), separated by striking dark features, and the central double star of 7.6 mag and 8.7 mag; it was catalogued twice by William: as N6 and N40.

On 3 May 1783, Herschel saw "Two Nebulas close together; I suppose they are Messiers 20th & 21st. Both resolvable into stars; the preceding however leaves no doubt tho' I suppose a higher power & more light would confirm the conjecture. 10ft power 350. The instrument will not conveniently bear a higher so low." On 2 August 1783, using the small 20-ft, he noted: "Neb. 8: Messier's, divided into two parcels one containing about 24 or 26 considerable stars. The other several stars but with a nebulosity about them which I can not resolve by 20ft 200, it seems to be the 8 Nebula by the description tho' the place answers better to the 20 & 21. A fixt instrument is wanting." And thereafter: "20 & 21 Neb, two parcels of stars, 20ft 200." A bit later he noted: "I believe [the two nebulae of 3 May] do not belong to the 20th and 21st but to the 8th Nebula." Obviously, Herschel observed M 8 on all dates. The confusion with M 20 and M 21 led to the case, discussed above.

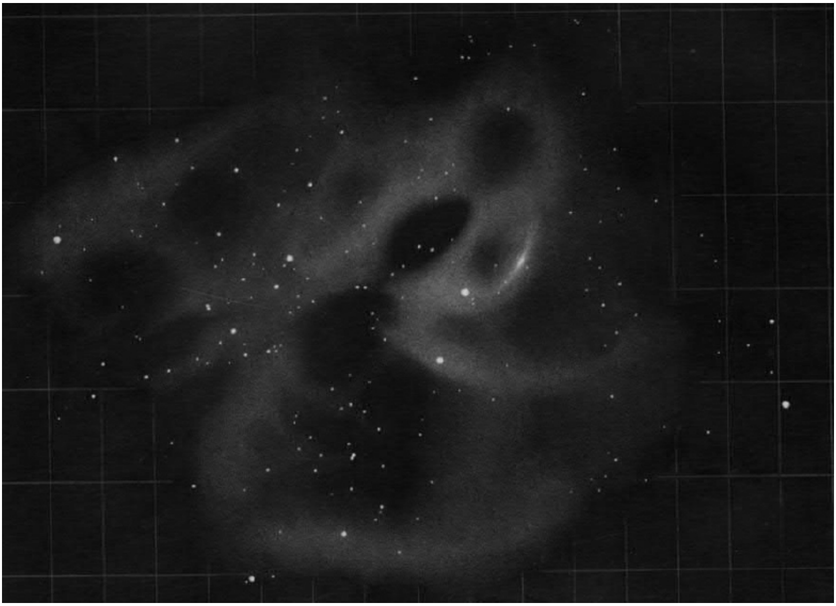


Figure 2-77: John drew the Lagoon Nebula M 8 on 27 June 1835

(18¼-in reflector; reproduced as a negative, south is up). The associated star cluster NGC 6530 is located in the left (eastern) part. 9 Sgr (6.0 mag) is the upper of the two bright stars.

In sweep 223 (22 May 1784), after Caroline had observed with the 20-ft while Herschel rested, there are three successive records:

[1] A larger, extended, broad, pretty bright nebula. The nebulosity of the milky kind, there are some pretty bright stars in it, but they seem to have no connection with it, being of very different sizes & colours & resembling the other stars that are every where scattered about in this neighbourhood […] This is probably the star surrounded with nebulosity mentioned by Messier in the 8th nebula of the Connoissance des temps. There is indeed one of the stars which are in the nebula that is somewhat larger than the rest and may be the only one he saw.

[2] A large, extended, broad nebula. The nebulosity is of the milky kind but fainter and more uniform, than the preceding; otherwise in situation and shape, it resembles it pretty much. It may be taken into the field with the preceding.

[3] The 8th Amas d'etoiles of the Connoissance des temps follows the above two nebulae immediately, but attending to them I did not take its passage; besides, it is indeed so coarsely scattered a cluster of large stars, that it would be difficult to determine its situation.

Prior to any interpretation of Herschel's records, one must recall what Messier wrote about his 8th object, observed on 23 May 1764:

Cluster of stars, which appears in a small refractor of three feet of the form of a nebula; but with an excellent instrument one notices nothing but a large number of faint stars; near this cluster is a pretty bright star, surrounded by a faint glow; this is the ninth star of Sagittarius, of seventh magnitude, after Flamsteed: this cluster appears in an elongated form, stretching from northeast to southwest, between the bow of Sagittarius & the right foot of Ophiuchus.

Note that the French astronomer speaks of two neighbouring, but different objects: a cluster of faint stars and a nebula around 9 Sgr.

Thus, M 8 is both, nebula and star cluster, a fact that has confused Herschel.

No doubt by position and description, his first object is the Lagoon Nebula around 9 Sgr (NGC 6523). In the sweep record [1], it is called "8th nebula of the Connoissance des temps". But this designation is applied also to the third object [3], which is certainly the star cluster NGC 6530. According to Messier and Herschel, M 8 should be NGC 6523 and NGC 6530. But what about the new object [2], catalogued as V 9 (NGC 6526)? Correcting a position error of 1° in PD, the place is 8' southeast of 9 Sgr. This coincides with the bright, oval south-eastern part of M 8, beyond the dark lane. The description fits well.

Unfortunately, there is another observation of M 8, made on 12 July 1784 in sweep 236, which increased the confusion: "(The No. a little uncertain because the index board stood on the ground, but was supposed would have shown 153.) Extensive milky nebulosity divided into two parts, the most northern part is the strongest and of more than 15' extent; the southern one is followed by a parcel of stars." Being aware that his place could be wrong, Herschel nevertheless catalogued the nebula as a new object V 13 (NGC 6533). However, this again is M 8. In the paper of 1785, he writes about V 13:[495] "the southern part is followed by a parcel of stars which I suppose to be the 8th of the *Connoissance des Temps*." So we end up with Messier's M 8, two Herschel objects (V 9, V 13) and four catalogued by Dreyer (NGC 6523, NGC 6526, NGC 6530, NGC 6533). The connection is: V 13 = NGC 6523 = NGC 6533 = M 8 (nebula), NGC 6526 = V 9 (part of the M 8 nebula). NGC 6530 = M 8 (cluster).

29 different Messier objects were observed in the second half of 1784, three for the first time; 24 had their premiere with the 18.7-inch. The new observations will now be discussed.

On 12 July (sweep 236)[496], Herschel viewed two Messier objects: the globular clusters M 22 in Sagittarius and M 30 in Capricornus. On the 13th (sweep 237) we have three more: M 6, M 69 and M 70. The extremely southern open cluster M 6 in Scorpius (Butterfly Cluster) was seen for the first time in the 18.7-inch reflector.[497] The globular clusters M 69 and M 70 in Sagittarius were new for him;

both appeared with a "faint red colour".

On 15 July (sweep 238), Herschel viewed the open cluster M 16 in Serpens and the globular cluster M 72 plus the nearby asterism M 73 in Aquarius (Figure 2-78). In the literature, it is often stated that M 16 is a nebula, but Messier clearly refers to a cluster.[498] Herschel confirmed this: "A cluster of coarsely scattered stars." Immediately after M 16 and 2° northeast, he saw an unknown 6 mag star (U[138]), "the largest of several in the finder". This is the open cluster NGC 6625 in Scutum. The object was not catalogued. M 72 in Aquarius appeared as usual. However, the globular cluster is among the few objects later observed with the 40-ft reflector. On 30 October 1810, he wrote:[499] "Having been about 20 minutes at the telescope to prepare the eye properly for seeing critical objects, the 72nd of the Connoiss. came into the field. It is a very bright object. It is a cluster of stars of a round figure, but the very faint stars on the outside of these sorts of clusters are generally a little dispersed so as to deviate form a very perfect circular form; the telescopes which have the greatest light show this best."

Back to 1784. Shortly after M 72 and 1.3° east, Herschel saw "several coarse patches of a few stars, one of which I suppose to be the 73rd of the Connoiss. des temps." On 28 September 1783, he had sounded more certain: "73 Nebula, consists of a few stars arranged in a triangular form. No nebulosity among them." Messier had written "contains some nebulosity". Actually, M 73 is only a quartet of 10–11 mag stars within 1' (asterism). A last observation of 30 October 1810 with the 10-ft confirmed this.

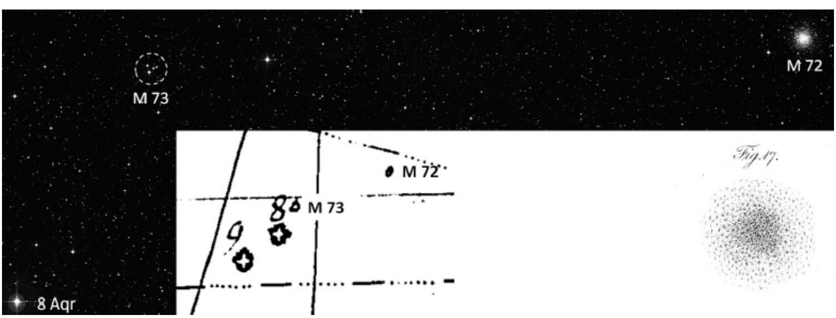


Figure 2-78: M 72 and M 73 in Aquarius, about 1.3' east, plotted as dots in the *Atlas Coelestis*; note the wrong place of M 73 relative to

the star ‘8 Aqr’ (not in the *British Catalogue*). Right: William’s sketch of 30 October 1810 (with 20-ft).

Sweep 241 on 19 July was interrupted: “Lord Palmerston saw the milky way through my great reflector, and admired the great number of the stars into which it was resolved.”[500] Because there was no specific target, the observer change at the chair was not a problem. After the visit, Herschel observed the Dumbbell Nebula M 27, culminating at midnight. The view was spectacular (Figure 2-79):

The nebula in Vulpecula I suppose to be a double stratum of stars of a very great extent. The ends next to us are not only resolvable nebulosity, but I really do see very many of the stars mixt with resolvable nebulosity; farther on the nebulosity is but barely resolvable and ends at last in milky whitishness of the same appearance as that in Orion. The idea I form of the shape of the strata is [here sketches are given]. These two being laid on each other A on A, and viewed from B so as to have the small round end A foremost may produce the appearance of this curious nebula.

Obviously, Herschel saw M 27 consisting of stars – another proof of his idea that all nebulae are clusters, though often disguised due to their distance. Thus, true nebulosity did not exist. Another observation in sweep 415 (17 July 1785) yielded nothing new. He saw the nebula again on 3 August 1799 (not in a sweep): “With 157 two patches of nebulosity close together. With 300 there are many small stars in it but they seem only to be those of the milky way projected upon the nebulosity. There are no signs of its being resolvable. It is a very wonderful object.” It is interesting that with the newly applied magnification (300×), using the eye-piece No. 5, the object did not appear ‘resolvable’. Obviously, the optical effect of a stellar substructure was stronger at a lower power. Finally, on 23 December 1805, now using the X-foot, Herschel noted: “It is a wonderful phenomenon.”

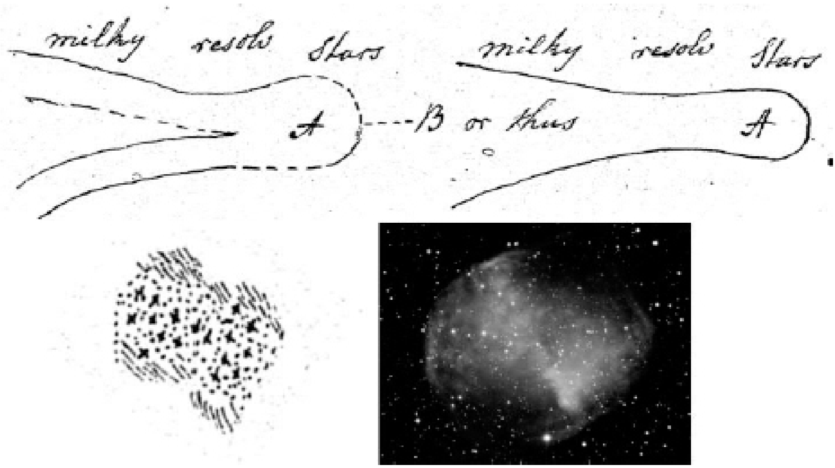


Figure 2-79: Herschel's sketch of the Dumbbell Nebula M 27 in Vulpecula, made to demonstrate the unusual structure of the object (see text).

That a globular cluster appears 'resolvable' or even 'resolved' is obvious. But what about galaxies, planetary nebulae or emission nebulae? What could cause the impression of 'resolvability' if there is absolutely no physical reason? Of course, Herschel and many eminent visual observers, like Lord Rosse, entertained an illusion. But it is also possible that the mirror was responsible for the phenomenon. Its metal surface, polished by a machine and less homogeneous than a modern glass/aluminium one, could generate a 'mottled' structure when extended nebulous objects are imaged. Any explanation of such illusions should also consider the subjectivity of visual observing. There were no objective images and the physical nature of the nebulae was unknown. If a nebula is observed unbiased (e.g. for the first time), a description or drawing can strongly deviate from reality. False images easily appear, especially when gazing at a faint object over some time at higher magnification. On the other hand, known structures are perceived much easier than unknown ones. But sometimes this leads to a curious effect: one sees the wanted structures, though they actually are out of reach of the telescope. To counteract the often-strange conspiracy of eye and brain, a large portion of self-criticism is needed. Thus, the observer and his condition are an essential element. It is interesting that William (and later John as well) saw

some galaxies and emission nebulae ‘resolvable’ or even ‘resolved’, but there is no evidence of this from Caroline.[501]

Back to Messier objects. The globular clusters M 14 in Ophiuchus and M 2 in Aquarius were viewed on 21 July (sweep 242).[502] For M 14 the “daylight is yet too strong”. M 2 appeared as “A cluster of stars extremely compressed in the middle and diminishing suddenly not a manner of a round solid but rather like the frustum of a cone whose base is turned towards the eye.” Like M 72, this globular cluster is among the few objects observed with the 40-ft reflector. The observation was made on 4 September 1799: “It appeared very brilliant and luminous. The scattered stars were brought to a good well determined focus from which it appeared that the central condensed light was not owing to confusion arising from the aberration of the scattered light but was owing to the multitude of stars the appeared at various distances behind and near each other. Besides, I could actually see and distinguish the stars even in the central mass. Power 240.”

Herschel saw something new on 7 August (sweep 245), the very compact globular cluster M 75 in Sagittarius, though with "too much moonlight". In the next night (sweep 246), he tried it earlier: "I saw the stars of it so as to be able to count some of them. It is however next to easily resolvable." Immediately after, the red star RT Cap (8.9 mag) was found and listed as U203: "A star of very deep, fine, garnet colour, 9 m." It is known as John Herschel's Ruby Star. John independently found the object 46 years later at Slough (see Table 2-11).[503] On the 18th (sweep 252), William saw M 71 in Sagitta for the first time in the 18.7-inch: "A very compressed cluster of stars". Although classified as globular cluster (concentration class XI), it more resembles a dense open cluster.

On 14 October (sweep 289), Herschel observed the face-on galaxy M 74 in Pisces: "Easily resolvable some stars visible in it; the coma extremely faint at the edges, and not resolvable." There is no hint that he had noticed the two spiral arms, which later were so evident at Birr Castle (Figure 2-145).[504] No other observation of the object was made with the 20-ft. On 15 October (sweep 292), while sweeping in Taurus, Aldebaran crossed the field. Its brightness (0.9 mag) interrupted the observation for 30 minutes. At the end of the sweep, Herschel discovered "A most beautiful garnet coloured star, 8m." The remarkable star, catalogued as U327, is BL Ori (see Table 2-11).

Three other bright stars were seen by the end of the year. On 7 November (sweep 309), Herschel encountered Bellatrix (1.6 mag) and Betelgeuse (0.6 mag) in Orion. He wrote about the latter: "Notwithstanding the light of the star, I counted more than 130 stars about α Orionis putting it successfully in the circumference of the field, so that it gives a circle of 30' diameter." On 9 December (sweep 333), the 1.8 mag star δ CMa was seen.

The bright globular cluster M 15 in Pegasus was observed on 19 October (sweep 299). Impressed by the object, Herschel wrote: "A beautiful cluster of very compact & numerous stars, the most compressed part about 2' diameter, the next about 7 or 8'; and all the stars within about 15' seem still to belong to the same by the [red?] colour, the size, the regular scattering and the gradual accumulation. The general figure is round; but within the space of 6

or 7' the stars are arranged in a sort of a square. I examined it also with No. 4 & 5 [240×, 300×] and it shewed the same appearance." We know about two attempts to view M 15 with the 40-ft. On 31 October 1810, Herschel wrote: "I set the telescope on the 15th of the Connoiss.; the change of temperature condenses the moisture of the atmosphere on the back and rim of the mirror in such a manner that it actually keeps on dropping into the tube. I dare not open the face of it now, but suppose that the same condensation at least in part, takes also place on the polished surface." He tried again on 26 November: "There has been an evening to see the cluster on which the instrument has been Oct. 31 and now day light interferes with an observation of it this year." M 15 also was Herschel's last Messier object. On 29 October 1817, the 10-ft was stopped to a smaller aperture: "I viewed the 15th of the Con. in the 10 feet reflector with an aperture confined to 4.5599 which gave the instrument a gaging power of 14; it shewed the object like a nebulous patch gradually brighter in the middle."[505]

On 16 November (sweep 316), Herschel viewed the Pleiades (the only time in a sweep). The stars 17 and 20 Tau (Maia) were registered. Unfortunately, Merope was not on the path. Perhaps his keen eyes would have perceived the famous nebula (NGC 1435), south of the 4.2 mag star.[506] In sweep 317 (on the same night), the Crab Nebula M 1 was examined for the first time with the 18.7-inch: "Very bright of an irregular triangular figure, resolvable." A second observation was made on 26 December 1785 (sweep 493). H Geminorum was used as reference star, known from the Uranus discovery. The planet was observed after the sweep. Since 1781, it had moved 18° eastwards, now standing in central Gemini. The nearby open cluster NGC 2129, found on 6 February 1782, was revisited. Shortly after, Herschel discovered the open cluster NGC 2158 (VI 17) in Gemini: "A very compressed cluster of very small stars, very rich." The object is only 26' southwest of M 35 (not observed). NGC 2158 was re-observed in sweep 374 on 11 November 1785 (now M 35 was viewed).[507]

The globular cluster M 79 in Lepus had its premiere in the 20-ft on 17 November (sweep 322). The 7.7 mag object was seen as "A fine cluster of stars, near 3' diameter, extremely compressed but completely resolved." M 79 had been seen twice with the 7-ft; later

it was observed three times with the 10-foot reflectors. On the 20th, a well-known target appeared, M 93. Caroline had independently found the open cluster on 26 February 1783. On the 20th (sweep 326), William discovered the first of two objects in the southern constellation Pyxis: the 10.4 mag galaxy NGC 2613 (II 266).[508] Because Flamsteed had not measured stars in the region south of Hydra, ρ Pup was used.

On 13 December 1784 (sweep 340), Herschel noted: "In this sweep I found the faint kind of suspected nebulosity again as before at 0^h 10'; but moving the telescope sideways to a part 10 or 12 degrees preceding [west] when I found B [bottom of sweep] very poor I could perceive no difference and believe this kind of deception is owing to the snow which covers the ground, the aurora that illuminate the snow, and a pretty high wind that agitates the air. But unless this had been done at the time this surmise may be erroneous having been in the light."[509] Reflections and stray light could cause false perceptions. Like the year before, the winter was nasty.

Figure 2-80: William Herschel's portrait as appearing in the February 1785 issue of the popular *European Magazine*, edited by Charles Hutton.

Already on 12 November, Herschel had received a letter from Charles Hutton, editor of the popular *European Magazine*, which appeared monthly in London. He was asked him to write a short autobiographical memorandum for the January 1785 issue. A portrait had already been made. With the aid of Caroline, William immediately wrote a text and sent it to London. Undoubtedly, the basis was his 'Memorandums from which a historical account of my life may be drawn'.[510] The tight schedule was adhered to and the January issue was on the market on 1 December. The portrait appeared in the *European Magazine* for February 1785 (Figure 2-80). The text, published by Hutton, treats Herschel as a third person. It describes his early years in England and the change from music to astronomy at Bath. In the main part, telescope making and his changing interest from the Solar System to stellar astronomy is treated. Finally, the author gives an overview on Herschel's publications in the *Philosophical Transactions*.[511]

2.2.7. Summary of 1784

Table 2-21 gives the statistical data of the sweeps made in 1784, starting with no. 76 on 16 January and ending with no. 350 on 21 December. The extraordinarily successful year yielded 16 all-time records (see 'Remarks').

Category	Value	Remarks
number of nights	128	*record*
longest continuous period (days)	10	4 – 13 September
longest break (days)	18	24 May – 11 June (bad weather?)
number of sweeps	275	*record*
sweeps per night (maximum)	18	23 Jan., *record*
mean night (hours)	3.9	
longest night (hours)	12.3	23 Jan. (observing time 8.1 hours)
lowest elevation (°)	8	13 July
highest elevation (°)	74	PD 55°, several sweeps
lowest PD (°)	34	

observed objects	793	*record*
objects per night (mean)	6.1	
sweeps without objects	92	*record*
new objects (all)	648	
uncatalogued objects	4	Table 5-5
re-observed objects	145	
most productive night	17 Apr.	57 objects
new objects: first	17 Jan.	NGC 1896 (*Grp Aur)
last	20 Dec.	NGC 4179 (Gx Vir)
brightest (mag)	5.7	M 33 (Gx Tri)
faintest (mag)	15.5	NGC 2843 (Gx CNC), record
smallest (")	16	NGC 6629 (PN Sgr), record
multiple	55	46 pairs; *record*
Messier objects:	93	*record*
first observation	22	*record*
first with 20-ft	61	*record*
new stars: double	22	*record*
new garnet stars	4	*record*
star gages	643	*record*
vacant places	78	*record*

Table 2-21: Sweep statistics for 1784.

The year brought many new methods and technical improvements. In the January break the observing chair was installed, followed by the ‘PD string’, bell mechanism and quadrant. Caroline created a table of Flamsteed stars, brought into in PD zones, and took over writing the *Journal*. The papers on the ‘construction of the heavens’ and the ‘second catalogue of double stars’ were read to the *Royal Society*. The Herschels had an illustrious visitor (Faujas), who described the observational work at Datchet. Interesting objects were seen: M 49, M 105 trio, Veil Nebula and the ‘hole in Scorpius’. William discovered his faintest object of all. Eastern sweeps were made to observe the Andromeda Nebula and its vicinity. In November, Herschel sent his autobiographical manuscript to the European Magazine.

2.3. 1785 – another busy year

2.3.1. A new equinox and Herschel's second paper on the 'construction of the heavens'

At the end of 1784, Caroline stopped copying sweep records from the 'Original' (*Sweeps* series) to the *Journal No. 10A*. It ends with the last sweep of the year (350), made on 21 December. The final entry concerns an innovation:

It appears now plainly that my late improvements in AR and PD have so far succeeded that I now should use the places of the stars reduced to the present time; but having registered all my sweeps in the time and PD of Flamsteed, I shall use them both till I may have leisure to alter my register of sweeps. The greatest inaccuracy now remaining is owing to the clock not having a compound pendulum, but I shall endeavour also to keep an account of its errors, which I have found formerly been very considerable.

This announces an equinox change from 1690 (Flamsteed) to 1785 (date). The first record for 1785 concerns sweep 351, made on 6 January. It is written down at the end of *Sweeps No. 3*. However, the positions for the reference stars are still for 1690. There are two more sweeps in the volume, 352 and 353 (6 January), also using 1690. Then Caroline opened *Sweeps No. 4*, copying the data of sweep 351. But now the positions are for 1785. To get them, she precessed the 1690 positions, listed in her first zone catalogue of Flamsteed stars. However, no new table was created (which would allow an easy access to all stars). Without which, Caroline had to calculate the new positions individually by applying the annual precession, given in her zone catalogue. Curiously, sweep 352 is omitted in the new volume, but not 353. From this sweep on, she lists the 1690 position and the precession for 1785 to calculate the differences for the clock and PD index readings. Not given is the object position for 1785; we find them beginning with sweep 440 on 24 September 1785, when the 'PD clock' was installed. This made the readings and calculations much more transparent.

The year 1785 started with another paper on the 'construction of the heavens', continuing that of 1784. The printed text is signed

‘Datchet near Windsor, January 1, 1785’. This is a bit curious, as it contains observations made until 10 January.[512] The paper was read to the *Royal Society* on 3 February and appeared in Volume 75 of the *Philosophical Transactions*.[513] It mainly treats the results of Herschel’s star gages, performed in the sweeps. The theoretical analysis of the counts led to the star distribution in a section of the Milky Way (see section 4.1.2).

A part of the paper concerns the observation of nebulae and star clusters made in 1784. This includes the existence of ‘nebulous strata’ and remarkable objects, including the ‘hole in Scorpius’, found near the globular cluster M 80; it is featured in the section ‘An Opening in the heavens’ (see section 4.1.5). However, Herschel starts with a ‘theoretical view’ about the ‘Formation of nebulae’. He describes the dynamical evolution of a system of almost uniformly distributed stars, based on Newton’s theory of gravitation. Five ‘forms’ are defined, i.e. structures, representing the possible final states when stars of different sizes interact freely. In the description of Form I, Herschel defines the term ‘globular cluster’:[514]

In the first place, since we have supposed the stars to be of various sizes, it will frequently happen that a star, being considerably larger than its neighbouring ones, will attract them more than they will be attracted by others that are immediately around them ; by which means they will be, in time, as it were, condensed about a center; or, in other words, form themselves into a cluster of stars of almost a globular figure, more or less regularly so, according to the size and original distance of the surrounding stars.

Form II represents irregular clusters. Form III is a ‘stratum of stars’, built by “long extended, regular, or crooked rows, hooks or branches”. Form IV is a more complex structure with stars and clusters, while Form V describes ‘vacant’ regions, like that in Scorpius.

Concerning the ‘nebulous strata’, Herschel was fascinated “of that remarkable collection of many hundreds of nebulae which are to be seen in what I have called the nebulous stratum of Coma Berenices”.[515] He further wrote that “the nebulae of the stratum of the Coma are brightest and most crowded just opposite our situation, or in the pole of our system. As soon as this idea was

suggested, I tried also the opposite pole, where accordingly I have met with a great number of nebulae, though under a much more scattered form." The term 'pole of our system' means the North Galactic Pole (NGP), located between the stars β and γ of Coma Berenices. The rotation axis of the Milky Way points in that direction. The South Galactic Pole (SGP) is located in Sculptor, near the border to Cetus. Here we find the bright galaxy NGC 253, discovered by Caroline. Indeed, William has seen many nebulae in the NGP region, but it sounds strange that he claims to have also found "a great number of nebulae" near the SGP.[516] The paper contains the chapter 'Phenomena at the Poles of our Nebula' in which he wrote "that there is a remarkable purity or clearness in the heavens when we look out of our stratum [Milky Way] at the sides; that is, towards Leo, Virgo, and Coma Berenices, on one hand, and towards Cetus on the other".

Some remarkable objects are treated in the chapter 'Enumeration of very compound Nebulae or Milky-Ways'. Herschel wrote:

As we are used to call the appearance of the heavens, where it is surrounded with a bright zone, the Milky-Way, it may not be amiss to point out some other very remarkable Nebulae which cannot well be less, but are probably much larger than our own system; and, being also extended, the inhabitants of the planets that attend the stars which compose them must likewise perceive the same phenomena. For which reason they may also be called milky-ways by way of distinction. My opinion of their size is grounded on the following observations. There are many round nebulae, of the first form, of about five or six minutes in diameter, the stars of which I can see very distinctly […] Some of these round nebulae have others near them, perfectly similar in form, colour, and the distribution of stars, but of only half the diameter: and the stars in them seem to be doubly crowded, and only at about half the distance from each other: they are indeed so small as not to be visible without the utmost attention.

Herschel gives nine examples of 'milky rays'. The first three concern the Veil Nebula in Cygnus, discovered on 6 and 7 September 1784 (sweeps 258 and 259). He gives descriptions of the western part V 15 (NGC 6960) and eastern part V 14 (NGC 6992) – the latter

incorrectly appears twice. The fourth example is V 17, “a faint, extended milky Ray”. Herschel refers to his observations of 11 and 12 September (sweep 266 and 268). He did not notice that, actually, the large galaxy M 33 in Triangulum was seen. The fifth example is “a Streak of light” in Cetus: V 20 (NGC 247), found on 20 October 1784 in sweep 303. The sixth is “an extensive milky Nebulosity divided in two parts”, seen on 12 July 1784 (sweep 236) and catalogued as V 13 (NGC 6533). Herschel wrote that “the southern part is followed by a parcel of stars which I suppose to be the 8th of the Connoissance des Temps.” Actually, all parts belong to the Lagoon Nebula M 8 in Sagittarius. The seventh case is “a wonderful, extensive Nebulosity of the milky kind”, seen on 22 June 1784 (sweep 231): “It is the 17th of the Connoissance des Temps.” The eights is the Orion Nebula M 42, the ninth the Andromeda Nebula M 31. Herschel wrote about the latter: “The brightest part of it approaches to the resolvable nebulosity, and begins to shew a faint red colour.” He also mentions the companion NGC 205 (V 18): “my Sister discovered it August 27, 1783, with a Newtonian 2-feet sweeper. It shews the same faint colour with the great one, and is, no doubt in the neighbourhood of it. It is not the 32nd of the Connoissance des Temps.” Herschel’s remarks on the colour of M 31 and NGC 205 are interesting.[517] Actually, the central region of the Andromeda Nebula appears (at best) yellowish white (Table 2-22). Finally, Herschel treats M 27 in Vulpecula, seen as “a double stratum of stars of a very great extent, one end whereof is turned towards us” (Figure 2-79).

Despite of the obvious case of a ‘garnet star’, Herschel often perceived a red colour for non-stellar objects, mostly globular clusters, but also some galaxies and emission nebulae (Table 2-22). Agnes Clerke wrote:[518] “There is, however, reason to suppose that the symptomatic redness was only a subjective impression, not an objective fact. His colour-sense was not quite normal. The lower, to his perception, somewhat overbalanced the higher end of the spectrum, and his mirrors added to the inequality by reflecting a diminished proportion of blue light. Thus, he recorded many stars as tinged with red which are now colourless, yet lie under no suspicion of change.”

Object	Type	H	Con	Sw	Date	Description (WH)	Remarks
M 4	GC		Sco	223	22 May 1784	all stars are red	resolved
M 5	GC		Ser	409	5 May 1785	stars of a red colour	resolved
M 15	GC		Peg	309	19 Oct. 1784	stars of the same [red?] colour	resolved
M 31	Gx		And			faint red colour	Andromeda Nebula, no source
M 68	GC		Hya	550	28 Feb. 1786	all the stars red	resolved
M 69	GC		Sgr	237	13 Jun. 1784	faint red colour	resolved
M 70	GC		Sgr	237	13 Jun. 1784	faint red colour	resolved
NGC 205	Gx	V 18	And			faint red colour	M 110, no source
NGC 772	Gx	I 112	Ari	481	29 Nov. 1785	faint red colour perceivable	
NGC 2467	EN	IV 22	Pup	381	6 Mar. 1785	faint red colour visible	
NGC 5897	GC	VI 19	Lib	383	10 Mar. 1785	faint red colour perceivable	resolved
NGC 6144	GC	VI 10	Sco	224	24 May 1784	faintish dusky red colour	resolved
NGC 6316	GC	I 45	Oph	224	24 May 1784	faintish dusky red colour	resolved

Table 2-22: Cases of non-stellar objects, in which Herschel perceived a 'red colour'. All objects were viewed with the 20-ft (Newtonian design).

It follows the section 'A perforated Nebula, or Ring of Stars', featuring M 57, the famous Ring Nebula in Lyra. A tiny sketch is added (see Figure 1-31), due to an observation made on 9 September 1784 with the 20-ft, though not in a sweep. On 3 September 1799, Herschel observed it with the same instrument (again not in a sweep).[519] In 1805 and 1806, the planetary nebula was seen in four nights with the 10- and X-foot. It is astonishing that he never noticed the central star of 14th magnitude. The star was eventually discovered by Friedrich v. Hahn about 1795, with a 12-inch reflector of 20 feet focal length – built by Herschel![520]

Then 'Planetary Nebulae' are treated: "I shall conclude this paper with an account of a few heavenly bodies, that from their singular appearance leave me almost in doubt where to class them." He presents five examples of his 4th class. The first is IV 1 (NGC 7009), the famous Saturn Nebula near ν Aqr, discovered on 7 September 1782 with the 6.2-inch reflector. Herschel mentions seven micrometer observations, where the distance to a faint, nearby star, the position angle (orientation; see Figure 1-23) and the diameter of the nebula were determined. The other planetaries are IV 18 (NGC 7662) in Andromeda, IV 11 (NGC 6369) in Ophiuchus, IV 16 (NGC 6905) in Delphinus and IV 13 (NGC 6894) in Cygnus. Herschel writes about their nature:[521]

The planetary appearance of the two first [IV 1, IV 18] is so remarkable, that we can hardly suppose them to be nebulae; their light is so uniform, as well as vivid, the diameters so small and well

defined, as to make it almost improbable they should belong to that species of bodies. On the other hand, the effect of different powers seems to be much against their light's being of a planetary nature, since it preserves its brightness nearly in the same manner as the stars do in similar trials. If we would suppose them to be single stars with large diameters we shall find it difficult to account for their not being brighter; unless we should admit that the intrinsic light of some stars may be very much inferior to that of the generality, which however can hardly be imagined to extend to such a degree. We might suspect them to be comets about their aphelion, if the brightness as well as magnitude of the diameters did not oppose this idea; so that after all, we can hardly find any hypothesis so probable as that of their being Nebulae; but then they must consist of stars that are compressed and accumulated in the highest degree. If it were not perhaps too hazardous to pursue a former surmise of a renewal in what I figuratively called the Laboratories of the universe, the stars forming these extraordinary nebulae, by some decay or waste of nature, being no longer fit for their former purposes, and having their projectile forces, if any such they had, retarded in each others' atmosphere, may rush at last together, and either in succession, or by one general tremendous shock, unite into a new body. Perhaps the extraordinary and sudden blaze of a new star [supernova] in Cassiopea's chair, in 1572, might possibly be of such a nature. But lest I should be led too far from the path of observation, to which I am resolved to limit myself, I shall only point out a considerable use that may be made of these curious bodies. If a little attention to them should prove that, having no annual parallax, they belong most probably to the class of nebulae, they may then be expected to keep their situation better than any one of the stars belonging to our system, on account of their being probably at a very great distance. Now to have a fixed point somewhere in the heavens, to which the motions of the rest may be referred, is certainly of considerable consequence in Astronomy; and both these bodies are bright and small enough to answer that end.

In a note added in proof, Herschel presents two objects, found on 1 and 7 February 1785 (sweeps 364 and 368). The planetary nebulae are IV 26 (NGC 1535) in Eridanus and IV 27 (NGC 3242) in Hydra, respectively. It is remarkable that he does not mention the colour of

these objects, except NGC 7009, seen “of a blueish light” on 2 August 1788 (sweep 851). Actually, NGC 6369 appears light green, NGC 1535 light blue, NGC 7662 (Blue Snowball) blue-green, NGC 6905 (Blue Flash Nebula) pale green and NGC 3242 (Ghost of Jupiter) green.[522]

2.3.2. A competent visitor at Datchet: Jean Hyacinthe de Magellan

6 January was the first night used in 1785; three sweeps were made (351–353). The yield of the exhausting 11-hour marathon, resting only 1.5 hours, was plentiful: 14 new non-stellar objects.[523] The first discovery of sweep 351 was a galaxy in Cetus, NGC 850 (III 259). It also brought a nebula that was later sketched: the 10.2 mag barred spiral NGC 936 (IV 23) in Cetus. In sweep 353 another nebula was found, worthy of a sketch: NGC 2974 (I 61), a 10.9 mag galaxy in Sextans with a superimposed star.[524] The only Milky Way objects were the open cluster NGC 2286 (VIII 31) in Monoceros and the emission nebula NGC 2023 (IV 24). The latter is 23' southeast of Alnitak (1.9 mag), the eastern star of Orion’s belt. Herschel wrote: “A bright star [7.8 mag] with a considerable milky chevelure, little extended, 5 or 6' in length, and near 4' broad, it loses itself insensibly, I suspected some extensive milky windings in the neighbourhood but could not verify them; other stars of equal magnitude were perfectly free from this chevelure.” Because the inspection took several minutes, Herschel missed the even brighter and larger emission nebula NGC 2024 (V 28), only 30' north. The spectacular object had to wait until 1 January 1786.[525]

On that strenuous night of 6 January, Herschel had an interesting guest, Jean Hyacinthe de Magellan.[526] In Caroline’s room, he joined the observing until midnight. William only had an hour to talk with him. It’s hardly surprising that Magellan’s report reveals greater scientific knowledge than that of the French geologist Faujas:[527]

I have spent the night of 6$^{\text{th}}$ to 7$^{\text{th}}$ January at Mr. Herschel’s in the village of Datchet, near Windsor, and had the luck to hit on a fine night. He had erected his large 20-foot Newtonian telescope in his garden in the open air, equipped with a very simple and convenient mounting. A workman, standing below, turned a handle alternately

for- and backwards until a hammer strikes, as soon as the telescope has been raised or lowered by the width of the field of view. This motion is transferred by a wire into a nearby room; it turns a pointer on a disk, showing marks calculated in a table and representing the different elevation angles of the telescope. In this room sits Mr. Herschel's sister and she has Flamsteed's Atlas [*Atlas Coelestis*] before her. When he gives a signal, she writes down the declination and right ascension and other circumstances of the observation in the journal. In this manner, Mr. Herschel investigates the entire sky, without omitting any small part of it. He usually observes with a magnification of 150 (in diameter) und he assured that he would have completely surveyed all what comes up above the horizon in 4 to 5 years. He showed me a book, containing all his previous observations, and I was astonished at the amount of that what he had already done in the sky. With his telescope, he passes each time through 2° 15' in declination and lets each star pass at least three times through the field of view, so that it is impossible to miss anything. He has found almost 900 double stars about the same number of nebulae.

I went to bed about one hour after midnight, and up to that time he had found that night 4 or 5 new nebulae. The thermometer in the garden stood at 13° Fahrenheit (above zero), but in spite of this Mr. Herschel observed all through the night, except that he recovered a few minutes every 4 or 3 hours, going back and forth in the mentioned room. His sister shares his enthusiasm for astronomy and has a lot of knowledge of calculations etc. For several years Mr. H. has not left any hour to observe the heavens when the weather is clear, and this always in the open air, because he obviously is aware about the fact that the telescopes performs only well if their temperature is equal to that of the air. He tries to protect himself against the rough weather by the right clothing. Fortunately, he enjoys a good health and thinks about nothing else in this world but heavenly bodies.

That Herschel "lets each star pass at least three times through the field of view" would imply about three minutes per object, which is not confirmed by the records. Much more time was needed for the entire sweep in this case. Herschel telescopes were permanently exposed to the open air at all sites. Only tube-caps or mirror

coverings protected the sensitive optical parts against the weather.

On the 10 January (sweep 355), the 10.5 mag galaxy NGC 1052 (I 63) in Cetus was discovered; it was later sketched.[528] In sweep 356 (same night), Herschel saw the first of two remarkable open clusters, associated with bright stars: NGC 2353 (VIII 34) in Monoceros, dominated by a 6th mag star. The next case appeared on 31 January in sweep 363: NGC 2539 (VII 11) in Puppis located 12' northwest of the 5.8 mag star 19 Pup. With 6.5 mag the open cluster is the brightest object found in 1785.

The year also brought three examples of a galaxy near a bright star. On 10 April (sweep 394), Herschel discovered the 12.5 mag galaxy NGC 4213 (II 354), 10' west of 7 Com (5.0 mag). Another case is the 12.5 mag galaxy NGC 2110 (III 448) near 55 Ori (5.4 mag, 13'), found on 5 October in sweep 458. Even more interesting is the 11.8 mag NGC 450 (III 440), found on 1 October (sweep 448), located 12' northeast of 38 Cet (5.7 mag). It is among the few cases of a superimposed galaxy; the 15.0 mag companion is UGC 807, 1.5' off the centre.[529] Of course, this optical alignment was not perceived by Herschel: “Very faint, very large, requires great attention.” The three cases of galaxies near a bright star are seen in Figure 2-81.

There is a curious entry on 30 January (sweep 361): “Observ. forgot.” The reason for the confusion might have been the weather condition: “the wind too high and the weather bad. The tube had been quite down so that I expected the adjustment to be totally out.” There is neither a star nor a non-stellar object at the place in Gemini.[530]

On the 31st (sweep 363), the large emission nebula NGC 2359 (V 21) in Canis Major was found and sketched (Figure 2-82): “A broad extended nebulosity, in the form of a parallelogram with a short ray southwards from the south preceding corner, the nebulosity between the milky and resolvable almost of an equal brightness; but very faint. The parallelogram about 8' long and 5 or 6' broad, but ill defined. It was doubtful at first; but on giving a side motion to the telescope so as to compare it with the other parts of the heavens it appeared very plainly.” Herschel determined a position: AR $7^h\ 9^m\ 24^s$, PD 102° 56'. Here, the ‘side motion’ is explicitly mentioned, used to track objects for some minutes, by turning a hand-wheel

near the eye-piece. Afterwards, the tube was pushed back to the meridian position (see Figure 2-5). Of course, meanwhile the sky went to the west and Herschel now viewed a place with larger AR at the same PD. Indeed, the next discovered object was seen at AR 7^h 14^m 54^s, PD 102° 56', the open cluster NGC 2375 (VIII 35). Then Herschel continued with the 'sweeping motion' (changing the PD), finding another open cluster at AR 7^h 18^m 34^s, PD 101° 21' (NGC 2396 = VIII 36).

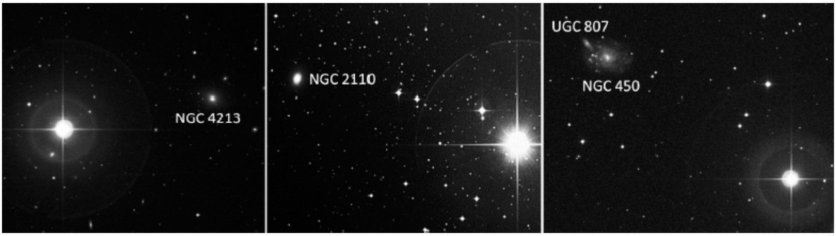


Figure 2-81: Galaxies near bright stars of 1785. Left: 7 Com; centre: 55 Ori; right: 38 Cet, NGC 450 (superimposes UGC 807).

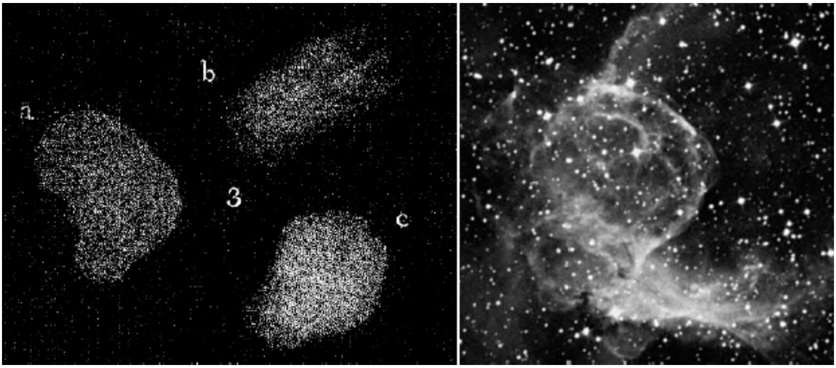


Figure 2-82: The emission nebula NGC 2359 in Canis Minor. On 31 January 1785 it appeared as three parts

Just before NGC 2359 was seen, Herschel encountered a "deep garnet coloured star about 12m". This is W CMa, catalogued as U^{440}. Two other 'garnet stars' were found in 1785 (see Table 1-15). The most spectacular is R Lep (U^{450}), seen on 4 February in sweep 365: "A bright garnet star about 9 m, a most beautiful colour." This is Hind's Crimson Star, found by John Hind in October 1845, using the 7-inch refractor at Bishop's Observatory, London. In 1850, the

astronomer wrote: “I may mention also a remarkable crimson star in Lepus of about the 7th. magn. the most curious object I have seen.”[531] On 8 October (sweep 461), Herschel saw 19 Pisc as “beautiful deep orange red; or pale garnet”. However, the credit goes to Tobias Mayer of Göttingen Observatory, who found the red star on 14 September 1756, noting ‘rubicunda’ (ruby red).[532]

On 1 February in sweep 364, Herschel found the first of seven planetary nebulae of the year: NGC 1535 (IV 26) in Eridanus. Though it is pretty bright (9.6 mag), the size is only 50". He wrote: “A very curious planetary, very bright, of a uniform brightness all but the edges which are ill defined; about half a minute in diameter with 240 proportionally magnified, perfectly round or perhaps a very little elliptical.” NGC 1535 was again seen on 3 October (sweep 452) in a very fine night: “It seems to have a small resolvable border, and is probably a very compressed cluster of stars at a great distance.”

The next exemplar was found on 7 February in sweep 368: NGC 3242 (IV 27) in Hydra, shining at 7.7 mag. Herschel wrote: “A beautiful, very brilliant globe of light, hazy on the edges, but the haziness going off very suddenly, I suppose it to be from 30 to 40" in diameter, perhaps a very little elliptical, the light of it seems to be all of the uniform intensity of a star of the 9th magnitude.” On 20 March 1786 (sweep 542), the object was seen “of a uniform white light”. In Herschel’s first catalogue of nebulae and clusters (1786), we read: “the light of the colour of Jupiter”. This led to the popular name Ghost of Jupiter.[533] NGC 3242 was shown to “Dr. Watson and Mr. Marsden” on 11 March 1788 after sweep 821.[534]

On 12 March (sweep 385), a ‘double planetary’ appeared 3° southwest of Castor; the components were classified as ‘faint nebulae’ II 316/17. This is NGC 2371/72. We read: “Two, faint, of an equal size, both small within a minute of each other; each has a seeming nucleus, and their apparent atmospheres run into each other, 240 shewed the same position from sp to nf.” A sketch was made (Figure 2-83). The 11.2 mag planetary nebula has a bipolar structure, much like M 76 in Perseus. It was again seen as “two nebulae” in sweep 791 (3 December 1787).

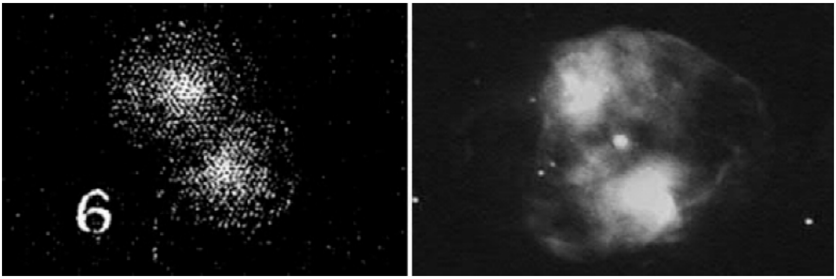


Figure 2-83: The bipolar planetary nebula NGC 2371/72 in Gemini, found on 12 March 1785.

On 7 April, Herschel discovered another planetary nebula: NGC 4361, located inside the quadrangle of Corvus; it was catalogued as ‘bright nebula’ I 65.[535] The 10.3 mag object, seen only once, was described as “very bright, pretty large, much brighter middle, the central brightness not round but as if it had two nucleuses pretty closely joined; the chevelure irregular round.” Probably, he has seen the 13.3 mag central star.

The final planetaries of 1785 appeared on 27 November and 28 December (sweeps 478 and 496). These are NGC 246 in Cetus and NGC 2022 in Orion. The former was classified as ‘large nebula’ V 25: “4 or 5 stars, forming a trapezium of 4 or 5' diameter; the enclosed space is filled up with milky nebulosity faintly terminated; the stars seem to have no connection with the nebulosity.” Due to its large size of 4', the 10.9 mag object has a low surface brightness, which makes it a rather difficult visual target.[536] Immediately after, a ‘companion’ of NGC 246 was found only 26' northeast: the 11.9 mag galaxy NGC 255 (II 472). NGC 2022 (IV 34) was the smallest object of the year, measuring only 40". Herschel noted: “Considerably bright, very small, like a star with a large diameter, with 240 it appeared almost like a planetary nebula, but very ill defined, a little extended, nearly of equal brightness throughout, except at the edges.” The tiny planetary nebula was seen again in sweep 666 (26 December 1786).

Some remarkable edge-on galaxies were found in 1785; the first on 7 February (sweep 369). This is NGC 5170 (V 22) in Virgo, showing an axis ratio of 8.2 (see Figure 2-185). Herschel wrote: “Much extended from sf to np, 5 or 6' long, the following part is the

brightest, pretty faint." This is one of the flattest galaxies, he has found (see Table 2-55). The next exemplar was seen on 6 April (sweep 393) in Leo: NGC 3987 (III 323) with axis ratio 6. It forms a pair with NGC 3993 (III 324) in the same field, 5' distant. One of the most spectacular edge-on galaxies was discovered in that night: NGC 4565 (V 24) in Coma Berenices. The 9.5 mag object with an axis ratio of 8 did not fit into the field of view: "A lucid ray with a very bright spot in the middle, the ray above 20' long and about 3 or 4' broad; extended from np to sf, making an angle of about 35° with the meridian; the angle very coarsely estimated. This nebula makes a beautiful appearance." Three edge-on galaxies were discovered in sweep 405 (1 May): NGC 5501 (III 412) in Canes Venatici, NGC 5529 (III 414) and NGC 5616 (III 419) in Boötes. The most extreme is NGC 5529 with an axis ratio of 8.6 ("very much extended"); see Table 2-55 and Figure 2-185. The sweep also brought a nebula, that was later sketched: The 11.6 mag galaxy NGC 5273 (I 98) in Canes Venatici.[537]

Four globular clusters were discovered in 1785, the first on 5 March (sweep 380): NGC 5634 in Virgo. The 9.5 mag object was not resolved (concentration class IV) and thus catalogued as 'bright nebula' I 70. On the 10th (sweep 383), Herschel saw NGC 5897 (VI 19) in Libra: "A beautiful large cluster of the most minute and most compressed stars imaginable. Different sizes and a faint red colour perceivable." The 8.4 mag object shows a very low star density (concentration class XI). Again, a red colour was seen (Table 2-22).[538] The third case had to wait until 25 September (sweep 440): NGC 6934 (I 103) in Delphinus. Although the globular cluster has the low concentration class VIII, it appeared unresolved. Thus, Herschel put in his class I ('bright nebulae') and not in VI, like other globular clusters. The final object was NGC 288 in Sculptor, discovered on 27 October in sweep 467: "Pretty bright, oval round, large, brighter middle, 7 or 8' large, 4 or 5' broad." Though no stars are mentioned in the 8.1 mag object, Herschel designated it as 'very compressed and rich cluster of stars' VI 20; the concentration class is X (see Table 2-18). NGC 288 is located only 36' northwest from the South Galactic Pole (SGP); 2.7° northeast is Caroline's nebula NGC 253 (not observed in that night). Of course, the globular cluster in Sculptor is the one with the highest (absolute) galactic latitude (-89°), followed by NGC 5053 (+79°) and NGC 4152

(+77°) in Coma Berenices.

On 6 March (sweep 381), a nebula was found in the Milky Way of Puppis: "Very faint, considerably large, easily resolvable, or rather some of the stars visible besides of the milky way scattered over it." The object is catalogued as 'very faint nebula' III 288. It is the 11.0 mag galaxy NGC 2566, located in Hubble's 'zone of avoidance', the region of strong absorption due to interstellar matter in the Milky Way disk. Only a few galaxies are visible here. Herschel found 30 galaxies with a galactic latitude between +15° and -15°. With +5.9°, NGC 2566 is nearest to the galactic equator, followed by NGC 7231 (II 606) in Lacerta (-9.0°) and NGC 2283 (III 271) in Canis Major (-9.4°); the galaxies were found in sweep 620 (24 October 1786) and 367 (6 February 1785), respectively.

2.3.3. An expedition to the north, the monster sweep 396 and the Coma Cluster

In autumn 1784, Herschel had turned the 20-ft by the 'round motion' from south (180°) to east (90°). Now, on 16 March 1785, it was oriented to the north (0°). This direction was used in sweeps 389 and 390–92; the latter were made on 4 April (the time-lag of 18 days was probably due to bad weather).[539]

Herschel wrote for sweep 389: "In this sweep which was made between the zenith and the north pole, the zero [top] is of course farther from the pole than the bottom of the sweep; therefore, the value of the numbers is to be taken from the zero to give the place of an object, and to be added to the place of a star in order to deduce the zero from it." He used the meridian passage above the pole star (at the larger elevation). Now the elevation is calculated by $E = 51^\circ + PD$. Herschel's intention was to inspect the sky at high declinations. The maximum δ so far reached in the south was +36° (PD 54°) in sweep 271; the galaxy NGC 404 near Mirach (β And) was seen at an elevation of 74°. The mounting was still not stable enough to allow higher elevations in a safe manner.

For the regular observations (south meridian), Caroline took the reference stars from her first zone catalogue of Flamsteed stars, restricted to PD ≥ 45°. Thus, it did not include the stars used in the

northern sweeps, which are 7 (β), 11 and 13 (γ) UMi and 27 UMa, with PDs of 13° to 17°. Their positions were taken directly form the *British Catalogue*; Caroline calculated the coordinates for 1785.

1785	Sweep	NGC	H	V	Con	Remark
16 Mar.	389	5607	II 331	13.4	UMi	= NGC 5620
16 Mar.	389	5808	III 311	13.5	UMi	not seen in sw 391
16 Mar.	389	5832	II 332	12.1	UMi	
16 Mar.	389	5836	III 312	13.9	UMi	
16 Mar.	389	6011	III 313	13.5	UMi	
16 Mar.	389	6094	III 314	13.2	UMi	
4 Apr.	390	2963	III 315	13.5	Dra	
4 Apr.	390	2985	I 78	10.4	UMa	
4 Apr.	390	3027	V 23	11.8	UMa	
4 Apr.	390	3065	II 333	12.5	UMa	pair
4 Apr.	390	3066	II 334	12.9	UMa	pair
4 Apr.	390	3147	I 79	10.6	Dra	
4 Apr.	390	3252	III 316	13.5	Dra	
4 Apr.	390	3343	III 317	13.4	Dra	
4 Apr.	390	3348	I 80	11.1	UMa	
4 Apr.	390	3364	III 318	12.8	UMa	
4 Apr.	390	3403	II 335	12.2	Dra	
4 Apr.	390	3516	II 336	11.7	UMa	
4 Apr.	390	3562	II 337	12.2	Dra	
4 Apr.	391	5620	III 319	13.4	UMi	= NGC 5607

Table 2-23: Galaxies found in the first northern sweeps; NGC 5620 and NGC 5607 are identical.

On 16 March, the telescope was rotated by the ‘round motion’ to the north and the tube elevated to about 68°. That was 6° lower than that for Mirach in sweep 271, but still pretty high; Herschel was sitting on his chair, 5.5 m above the ground. In sweep 389, Ursa Minor was inspected. Six objects were discovered, all are galaxies. Three are interesting: the 13.4 mag galaxy NGC 5607 (II 331), described as “faint, easily resolvable, pretty small”, NGC 5836 (III 312), located only 40' southeast of Kochab (β UMi), and the 13.2 mag galaxy NGC 6094 (III 314), appearing doubtful: “Extremely faint, very small, a little extended, may be only a patch of a few stars.”.

In the other night (4 April), the region above the pole was visited again, but now the focus was on Ursa Major and Draco. 13 objects were found, all are galaxies. Among them are three bright ones: NGC 2985 (I 78), NGC 3147 (I 79) and NGC 3348 (I 80), with 10.4, 10.6 and 11.1 mag, respectively. Also, a double galaxy was found: NGC 3065/66 (II 333/34) in Ursa Major; the components are 3' apart: "Two, small, pretty faint, brighter middle, the most north a very little larger and brighter that the southern one; otherwise much alike; not far from being in the same meridian." Finally, in sweep 391, a 14th object was discovered (III 319): "Suspected, excessively faint, very small." However, the position is only 12' east of II 331 (NGC 5607), the first object found in the northern mission. There is no other nebula near, so III 319 = II 331. Dreyer catalogued the 'new' nebula as NGC 5620. At the end of the sweep, Herschel encountered the 2.3 mag star Kochab. Nothing was found in sweep 392. With 20 discoveries, the first northern expedition was pretty successful (Table 2-23). Moreover, eight 'star gages' were made. During the sweep campaign, he carried out a total of 131 sweeps in the north, either above or under the pole.

In sweep 393 (6 April), Herschel returned to the south meridian. 21 galaxies were found in Leo and Coma Berenices at about 65° elevation. The brightest are NGC 4494 (I 83) and NGC 4725 (I 84) in Coma Berenices, with 9.8 and 9.4 mag, respectively. The latter was described as "brightness confined to a small spot; the rest being milky nebulosity". Sweep 394 and 395 were made on 10 April. While the first brought 29 galaxies, mainly in Leo, nothing was found in the second, covering a small portion of Hercules; it was early in the morning and Herschel saw "pretty much twilight". In sweep 394, a close pair was discovered: NGC 3651/53 (III 335/36), distance only 1.5': "Two, both very faint and very small, the most south is the faintest. I saw both very well with 240, about 2 or 3' from each other." Another pair, with 4.6' a bit wider, was later found: NGC 4002/03 (III 910/909).

11 April is the date of the most productive observing session Herschel has ever held. It took no longer than the previous ones, but it had a record yield. Two sweeps were made in the night: 396 and 397. The first began at 8:35 pm in "strong twilight and faint moonlight" and ended at 0:15 am (observing time $3^h\ 40^m$).[540] After

a one hour break, Herschel continued with sweep 397, which lasted another $2^h\ 20^m$. The night ended at 3:35 am. The total observing time was six hours. In sweep 396, he mainly observed in Leo Minor and Coma Berenices – right in the nebular 'stratum' (Figure 2-84). The second sweep covered parts of Boötes and Corona Borealis. The average declination (for both sweeps) was +28° (PD 62°), giving an elevation of 67°; the breadth was 2° 18'.

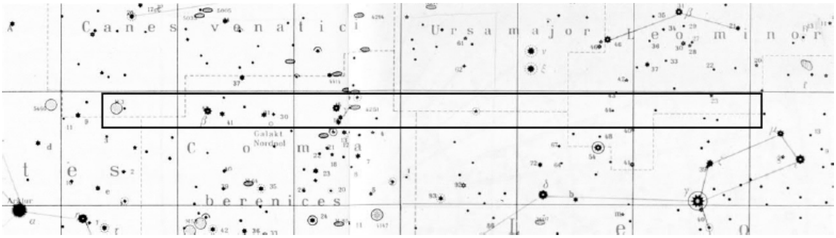


Figure 2-84: Sweep 396 stretched over Leo Minor, Ursa major, Coma Berenices and Canes Venatici (ending at M 3).

Altogether, 81 non-stellar objects were observed in the night, of which 73 were new. With the exception of two, all are galaxies. With 79 objects, sweep 396 is the record holder (every three minutes an object was seen); sweep 397 brought only two (both new). Eight Flamsteed stars were registered in sweep 396, seven in the following. Three unknown stars were seen. At the end of sweep 396, Herschel actually found time for two 'star gages' (another one was made in sweep 397). Here is the chronology, presenting the most interesting objects.

The first discovered object (seen at 8:47 pm) was the smallest of the year and among the faintest: "Suspected, extremely faint, a little elongated. I do not much doubt it; but there is too much light to verify it." It is amazing that Herschel saw the 14.9 mag galaxy NGC 3196 (III 348) in Leo when the sky still was not fully dark. This is due to the high surface brightness of the compact object and perhaps the combined light with a 15th mag star 30" east (Figure 2-85).[541] Already the next object, seen seven minutes later, was the opposite, the galaxy NGC 3245 (I 86) in Leo Minor: "Considerably bright, pretty large, much brighter middle, and the greatest brightness a little elongated." Another four minutes later, the third discovery, was again doubtful: "Suspected, 240 shewed a few small

stars with seeming nebulosity, and I rather suppose it to be a patch." Herschel has seen the 12.9 mag galaxy NGC 3265 (III 349) in Leo Minor. At 9:28 pm, a "very bright, very large" object was found, the 10.5 mag galaxy NGC 3486 (I 87) in Leo Minor. A special case was the edge-on galaxy NGC 3510 (II 365) in Leo Minor, seen at 9:31 pm: "about 1½' long but very narrow" (axis ratio 5).

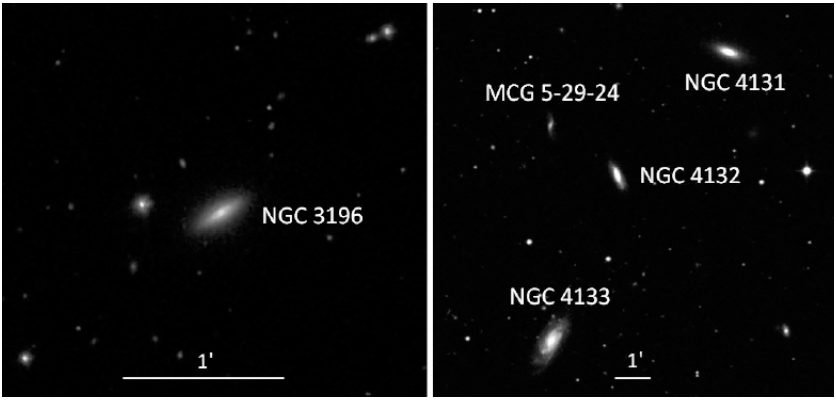


Figure 2-85: Objects discovered in sweep 396 on 11 April 1784. Left: the first, faintest and smallest, NGC 3196 (14.9 mag) in Leo. Right: a galaxy chain in Coma Berenices containing NGC 4131 (13.3), NGC 4132 (14.0) and NGC 4133 (12.3); perhaps Herschel also perceived MCG 5-29-24 (15.1).[542]

Between 9:35 and 9:38 pm, Herschel discovered three members of the galaxy cluster Abell 1185 in Ursa Major (Table 2-25).[543] These are NGC 3527 (III 350), NGC 3550 (III 351) and NGC 3552 (III 352). The latter two form a pair with a separation of 4.6'. Herschel wrote: "Two, both very faint and very small, the most south is the faintest, and but for the other could not have been observed." 10 NGC galaxies belong to the cluster.[544] Five are near to the pair; though fitting into the field of view, they were either too faint or off the sweep path. NGC 3527 is 45' west. At 10:27 pm, Herschel made a star gage in Leo – unusual in a situation with so many nebulae.[545] Indeed, when the 13.7 mag galaxy NGC 4004 (III 354) appeared, the task was immediately stopped after counting two fields. He wrote: "Very faint, very small, it was in the field I was gaging otherwise it would probably have been overlooked."

At 10:36 pm, Herschel noted “A deception detected.” This is a trio of 10–12 mag stars in Coma Berenices. A minute later, a nebular trio was found about 2° north; the galaxies NGC 4131/32/34 (III 356/57, II 371) build a 10' long chain: “Three, the time and number belongs to the largest which is faint, irregularly. I suspect a fourth, but could not stay to ascertain it, though I am pretty sure.” There is only one candidate for the fourth galaxy: MCG 5-29-24, located 2.3' northeast of NGC 4132 (see Table 5-5). It has a brightness of only 15.1 mag. Because Herschel has seen extremely faint galaxies in that April night, like NGC 3196 (14.9 mag), it is likely that he perceived this object in the field with the others (Figure 2-85). When he found a nebula, he was triggered to see another, often weaker, in the vicinity. As a single object, it was more likely to be missed. However, MCG 5-29-24 was not catalogued.

At 10:41 pm, Herschel discovered a stunning galaxy quartet in Coma Berenices. It covers an area of only 5.0' × 2.5' (see Figure 2-104). The compact group is called The Box.[546] The members are NGC 4169/73/74/75 (III 358, II 372, III 359, III 360), NGC 4169 is the brightest (12.2 mag), NGC 4174 the faintest (13.4 mag), though with a high surface brightness. NGC 4173, is extremely flat, measuring 5.0' × 0.7' (axis ratio 7). Herschel discovered all galaxies at the same time: “Four, the time and number belongs to the largest which is faint and small [NGC 4173]. The other three are fainter; forming a small quartile, the largest being the most north preceding side; all within 3 minutes.” A second observation was made on 3 February 1788 (sweep 805): “Four, forming a quadrangle; the place taken, is the center of it. The north preceding [NGC 4169] extended, considerably faint, small.” Herschel’s four galaxy quartets are listed in Table 2-29 and shown in Figure 2-104. At 10:44 pm, Herschel found a “faint, pretty small” object (III 375). Actually, this is a trio of faint stars, catalogued as NGC 4209 by Dreyer (John could not find it); see Figure 2-86.

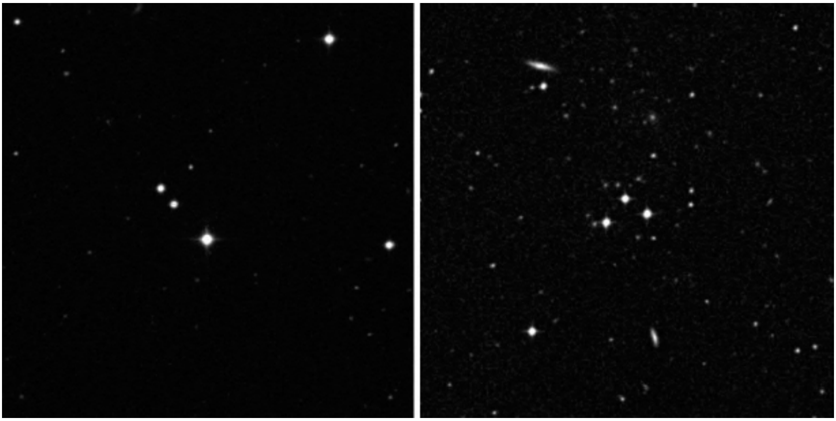


Figure 2-86: Herschel's two star trios. Left: NGC 4209 (III 375) in Coma Berenices, found in sweep 396 (11.3–14.5 mag); right: NGC 1498 (VII 3) in Eridanus with 13.5 mag stars (8 February 1784, sweep 136); images 7.5' × 7.5'.

Three minutes later, a 10.7 mag galaxy was found in Coma Berenices: NGC 4251 (I 89). At 11:05 pm an even brighter one followed: NGC 4559 (I 92), with 10.0 mag. Herschel wrote: "Extremely bright, very large and beautiful. 4 stars scattered over it, pretty much extended, from np to sf, the greatest brightness is not in the middle but more towards the following part, where 3 of the 4 stars are placed; the whole extend may be 10 or 12'." One can speculate if he has seen four of the six compact HII-regions of the galaxy, but they are too faint (14.5–15.5 mag).[547] Actually, there are three stars of 12–13 mag superimposed on the bright galaxy.

The highlight of sweep 396 started at 11:23 pm, when Herschel entered the Coma Cluster of galaxies (Abell 1656). It is located between right ascension $12^h\ 50^m$ and $13^h\ 10^m$ and declination $+26°$ to $+29°$ (the centre is about 2° northeast of the North Galactic Pole). The cluster contains about 3000 galaxies in an area of 4° diameter, most of them are very faint.[548] The central part, around the dominating galaxies NGC 4874 (11.7 mag) and NGC 4889 (11.5 mag), measures 1.5° × 1.0°. 65 members are catalogued in the NGC, 39 in the IC (Figure 2-87). Herschel is credited for 25 NGC galaxies (Table 2-25), 21 of which were discovered in sweep 396 (Table 2-24).[549]

Time	NGC	H	V	Size (')	Remarks
11:23	4793	I 93	11.6	2.9 × 1.5	
11:24	4798	II 382	13.2	1.0 × 0.7	
11:25	4816	II 383	12.8	1.3 × 1.1	
11:26	4827	II 384	12.9	1.4 × 1.2	
11:26	4840	II 385	13.7	0.7 × 0.7	
11:27	4839	II 386	12.1	4.0 × 1.9	
11:27	4841	II 387	13.0	1.0 × 0.7	double system
11:29	4869	II 388	13.8	0.8 × 0.7	
11:29	4874	II 389	11.7	1.9 × 1.9	dominating galaxy
11:29	4892	II 390	14.0	1.3 × 0.3	
11:29	4889	II 391	11.5	2.8 × 2.0	dominating galaxy
11:30	4908	III 363	13.2	1.0 × 0.8	
11:30	4911	II 392	12.8	1.2 × 1.1	trio
11:30	4921	II 393	12.2	2.4 × 2.1	trio
11:30	4923	II 394	13.7	0.8 × 0.8	trio
11:31	4927	III 364	13.8	0.6 × 0.4	
11:33	4944	II 395	12.9	1.5 × 0.5	
11:34	4957	II 397	13.0	1.2 × 1.0	
11:35	4961	II 398	13.6	1.6 × 1.1	
11:38	4983	III 365	14.0	1.1 × 0.7	
11:39	5000	III 366	13.2	1.7 × 1.4	

Table 2-24: In sweep 396 on 14 April 1785, Herschel discovered 21 galaxies of the Coma Cluster (Abell 1656).

Herschel's first discovery was the 11.6 mag galaxy NGC 4793 (I 93), described as "considerably bright". It is of similar brightness as the dominating galaxies, NGC 4874 and NGC 4889. The former was seen together with NGC 4869, 4' southwest: "Two, the time taken between them." Curiously, nothing is said about the brightness of NGC 4874. In the literature, Herschel is credited for discovering the much fainter galaxy NGC 4872, instead of NGC 4874. The 14.4 mag object is only 48" southwest. This claim is strange, because it would mean that he ignored a bright galaxy for a much fainter one! Moreover, there is a general brightness problem. NGC 4889 (11.5 mag) is described as "faint", whereas the 11.7 mag galaxy NGC 3277 (11.7 mag), found 2.5 hours earlier, was seen "very bright".

For NGC 4283 (12.1 mag), seen half an hour earlier, we read "considerably bright".

Actually, all descriptions of cluster members are pretty brief. Obviously, Herschel was in a hurry and not able to give reliable information. 17 objects were put in class II ('faint nebulae'), regardless of whether they were bright or faint.

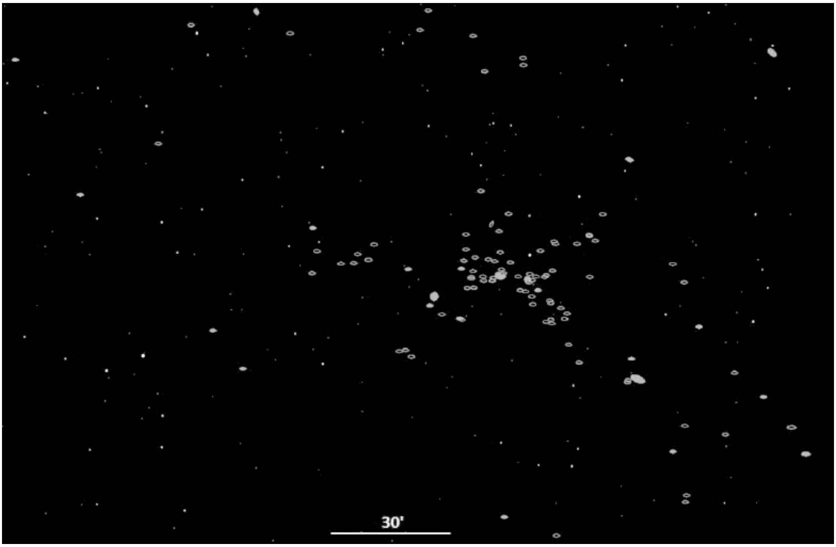


Figure 2-87: Herschel's discovered 25 galaxies in the Coma Cluster (filled ovals); the dominant members are NGC 4874, NGC 4889 (right of centre, see next figure). The 21 galaxies of sweep 396, are listed in Table 2-23.

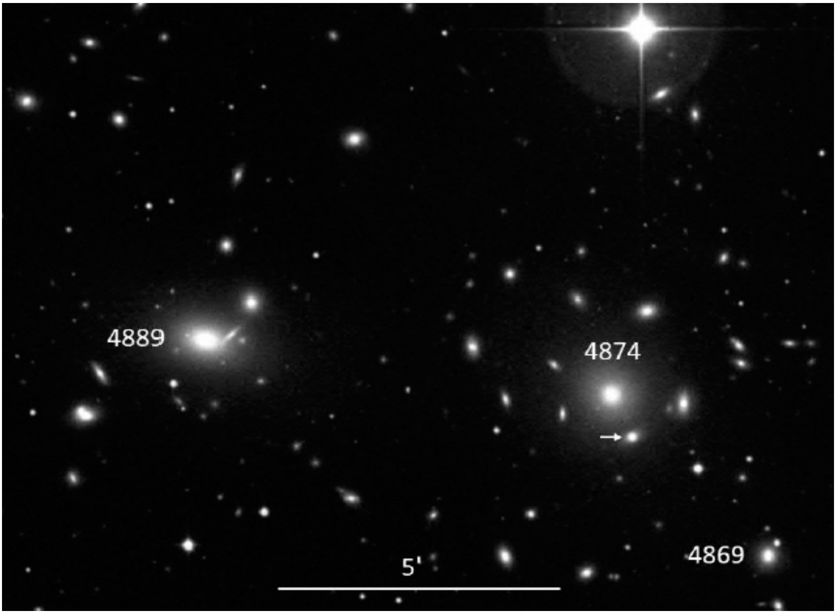


Figure 2-88: Herschel found three galaxies in the central part of the Coma Cluster; NGC 4869 (13.8 mag), NGC 4874 (11.7) and NGC 4889 (11.5). The 14.4 mag galaxy NGC 4872 (arrow) is incorrectly claimed as a Herschel find.

The galaxies NGC 4911/21/23 were seen in a single field: “Three, the two following pretty near each other; the south preceding about 8' distance.” Indeed, NGC 4921 and NGC 4923 are only 2.5' apart. NGC 4952 (II 396) was already discovered as III 303 in sweep 387 (13 March). Neither Herschel nor Dreyer saw an identity, so the 12.4 mag galaxy is also catalogued as NGC 4962. Herschel’s last find in the Coma Cluster was the 13.2 mag galaxy NGC 5000 (III 366).

It is a fact that Herschel did not recognize the part of the coma cluster that he was observing as a unit. In his view, the nebulae belong to the much larger ‘stratum of Coma Berenices’, which, in the modern view, includes the Virgo Cluster and some neighbouring aggregations. Table 2-25 lists 12 galaxy clusters, in which Herschel has found members.

Cluster	Con	NI	WH	Sweeps	NGC	H	V	Sw	Date	Remarks
Virgo	-	551	173	174, 191	4526	I 31	9.3	191	13 Apr. 1784	253 NGC + 298 IC; M 49, 61, 91 seen
Abell 1656	Com	104	26	396	4889	II 391	11.5	396	11 Apr. 1785	Coma Cluster; 65 NGC + 39 IC
Abell 1367	Leo	25	9	401–03	3842	III 378	11.8	402	26 Apr. 1785	Leo Cluster; 5.5° north of Denebola
Abell 426	Per	22	3	614	1275	II 603	11.9	614	17 Oct. 1786	Perseus Cluster; 2.2° east of Algol
Pegasus I	Peg	19	6	442	7619	II 439	11.1	442	26 Sep. 1785	8° southeast of α Peg
Abell 194	Cet	14	4	448	545	II 448	12.2	448	1 Oct. 1785	Cetus Cluster
Abell 347	And	11	3	614	910	III 571	12.2	614	17 Oct. 1786	1° southeast of NGC 891
Abell 1185	UMa	10	3	396	3550	III 351	13.2	396	11 Apr. 1785	
Local Group	-	9	1	-	185	II 707	9.2	786	30 Nov. 1787	M 31–33, NGC 185, NGC 205 seen
Abell 262	And	9	4	599	703	III 562	13.3	599	21 Sep. 1786	2° southwest of NGC 752
Abell 2197	Her	4	2	718	6173	III 640	12.1	718	18 Mar. 1787	5° northwest of M 13
Abell 2199	Her	2	2	-	6166	II 875	11.8	1015	30 May 1791	4° northwest of M 13

Table 2-25: All galaxy clusters, in which Herschel has found members. The Virgo Cluster and the Local Group stretch over several constellations. NI = total number of NGC/IC galaxies (see Remarks), WH = number of Herschel discoveries (all are in NGC); Sweeps = most discoveries; NGC = brightest discovered galaxy (followed by its data); Remarks: brighter members seen, found earlier by other observers.

At 11:52 pm, Herschel tried another star count, but “I stopped to gage otherwise I might perhaps have overlooked it”.[550] Here the 12.7 mag galaxy NGC 5116 (III 368) is meant. After this discovery, he left Coma Berenices to inspect parts of Boötes and Canes Venatici. At 0:07 am the 13.9 mag galaxy NGC 5251 (III 369) was seen in Boötes: “Suspected, extremely faint, very large, 240 shewed it larger an a little extended, but so obscure as not to remove all doubt.” Two minutes later he found the 13.4 mag edge-on galaxy NGC 5263 (III 370) in Canes Venatici, noting “much extended nearly in the meridian”. The finale of the monster sweep 396 was celebrated by an old friend: the globular cluster M 3 in Canes Venatici, located only 31' west of NGC 5263.

After terminating sweep 396, William and Caroline needed about one hour to recover. The following sweep (397) started at 1:07 am. Two galaxies in Corona Borealis were discovered: NGC 5958 (II 399) and NGC 6001 (III 371) with a brightness of 12.7 and 13.6 mag, respectively. The observations ended in Hercules at 3:30 am. The night, starting at 8:35 pm was long, exhausting – but extremely productive!

Concerning the number of discovered objects, the second place, after sweep 396 with 71, is occupied by sweep 405 on 1 May 1785. The night brought 42 new objects in 4.6 hours. Herschel inspected

parts of Canes Venatici and Boötes (see next section).

2.3.4. More galaxy clusters, uncatalogued objects and the move to Clay Hall

From 27 April (sweep 403) on, the position of the tube end was set by a 'bar table'. This allowed a more precise adjustment when shifting it towards the centre to reach higher elevations. Different to Figure 2-7, the observer now sits on a chair at the side. In the next night (sweep 404), a tube elevation of 77° was reached (Figure 2-89). The discovered object was the 11.7 mag galaxy NGC 3813 (I 94) in Ursa Major (PD 52° 15').

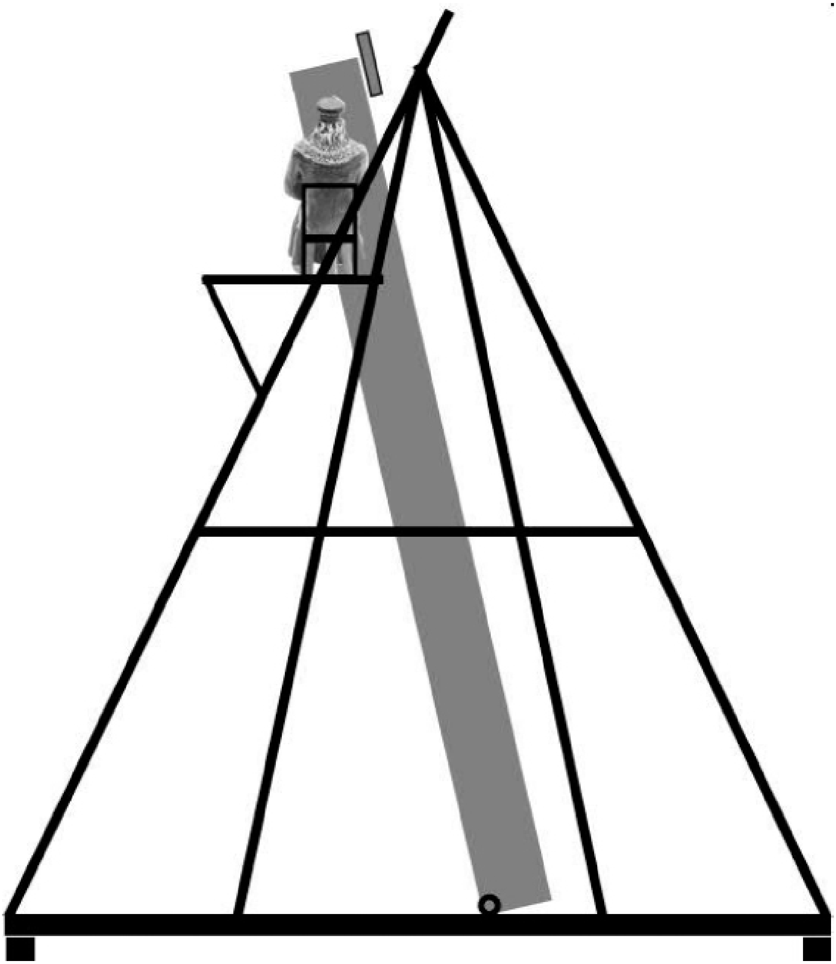


Figure 2-89: The bar mechanism in action. At a tube elevation of 77°, the observer sat on the chair at the side, high above the ground.

1785 again was a year of double and triple systems: 20 and five, respectively. On 7 February (sweep 368), the first pair was found: the spectacular double galaxy NGC 4038/49 in Corvus, known as The Antennae.[551] The companions are 1' apart. Herschel wrote: “Large, pretty bright, two joined together, the smallest south; or one opening with a branch very faintly joined.” There is only one catalogue entry for both, referring to the ‘planetary nebulae’ class: IV 28. Later John split it in the *Slough Catalogue* into IV 28.1 and IV 28.2 (h 1052/53). Another interacting pair was found on 8 February (sweep 371) in Hydra: NGC 2992/93 (III 277/78); the separation is 3'. We read: “Two, very faint, the most north and preceding is the largest. 240 shewed the same, distance 3 or 4'.” The duo was seen again in 1798 with the 25-ft ‘Spanish telescope’; it was the only non-stellar object, observed with this 24-inch reflector (see Table 3-13). Both pairs are presented in Figure 2-90. In the same night (sweep 372), a very close pair was seen in Corvus: NGC 4724/27 (III 280/II 298); the separation is only 54" (see Table 2-28).

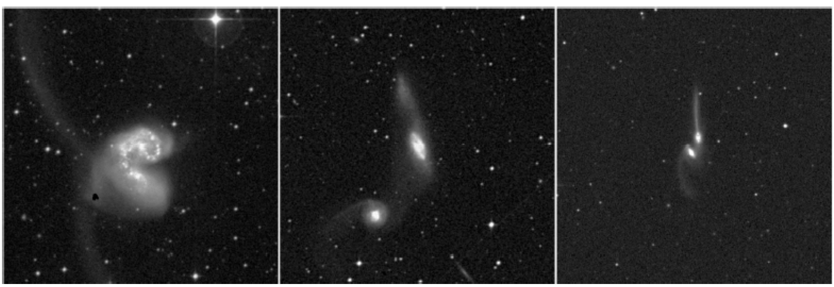


Figure 2-90: Three interacting galaxy pairs, found in spring 1785 (images 10' × 10'). Left: The Antennae, NGC 4038/39 in Corvus (10.3 mag). Centre: NGC 2992/93 in Hydra (12.2 mag, 12.5 mag). Right: The Mice, NGC 4676 (13.5 mag) in Coma Berenices; the pair was not resolved.

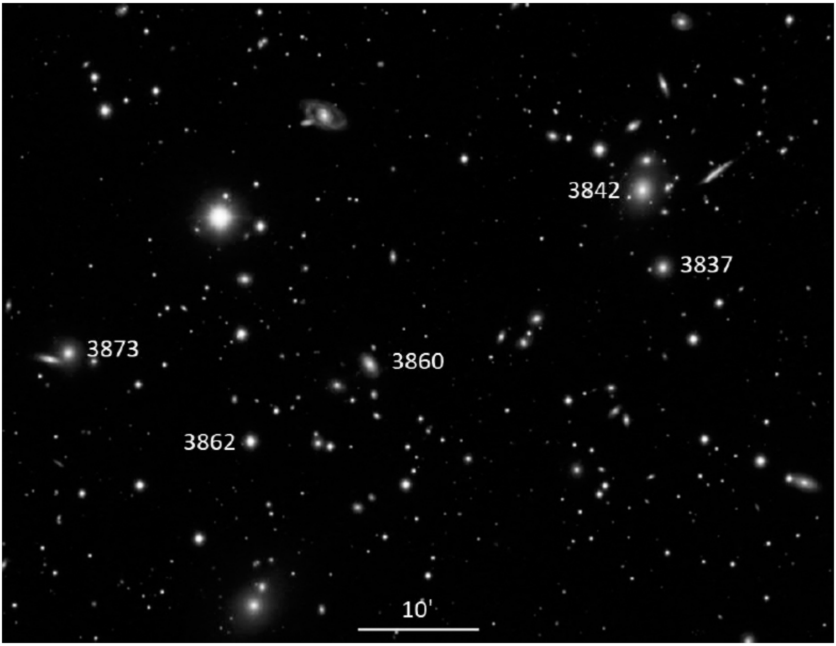


Figure 2-91: Herschel discovered five galaxies in the central part of the Leo Cluster (Abell 1367). The strange object 3' northeast on NGC 3842 is the extremely flat galaxy UGC 6697 (14.3 mag). Alas, due to the sweep path it was missed, like many other cluster members, though in the reach of the 20-ft.

On 5 March, Herschel discovered NGC 5426/27 (II 310/09) in Virgo: "Two, pretty bright, the northern one considerably large and much brighter middle. The southern one much less, and a little fainter, a very small star or two between them, but not connected with the, distance about 4' but the chevelures touch each other; nearly in the same meridian." The separation is only 2.3'; the two stars are real. The northern component, NGC 5427, is a face-on galaxy.552

On the 13th (sweep 387), Herschel encountered a strange object, oriented north-south: "Faint, much extended, in the meridian." Actually, this is a very close pair (separation 38"), catalogued as II 326 (NGC 4676). The object is commonly known as The Mice (Figure 2-90). He was unable to resolve it with the standard eye-piece (157 ×). Unfortunately, although available, a higher power

was not tried. In the same sweep, Herschel discovered the trio NGC 4278/83/86 (II 322/23, III 300) in Coma Berenices. The galaxies form a 9' long chain: “Three, all in a row, but of unequal size and brightness. The most following very faint.”

After his view of the Coma Cluster in sweep 396, Herschel encountered another galaxy cluster in April. Again, he did not recognize it as a unit. For him, of course, the crowding about 5° north of Denebola (β Leo) also belongs to the ‘stratum of Coma Berenices’. This is the Leo Cluster (Abell 1367), covering an area of 2° in diameter. Herschel found nine of 25 NGC galaxies (Figure 2-91; Table 2-25). NGC 3883 (III 372) and NGC 3805 (III 375) were seen on 13 and 25 March (sweep 398 and 401). On the 26th (sweep 402), NGC 3821 (III 376), NGC 3837 (III 377), NGC 3842 (III 378) followed.[553] Four members were discovered in the next night (sweep 403): NGC 3860 (III 386), NGC 3862 (III 385), NGC 3873 (III 387) and NGC 3884 (III 388). With 11.8 mag, NGC 3842 is the brightest galaxy of the Leo Cluster. It was seen as a pair with NGC 3837 (13.3 mag), separation 3.6'. The other members are about 12–15 mag.

On 14 April (sweep 400) Herschel was fascinated by an ‘electrical brush’, writing: “Very faint, just north of a small star, to which it seems to be an electrical brush preceding towards the north, but there is a little distance between the star and the brush. At first it resembles the 1st of my Fanshaped.” The object is the 12.5 mag galaxy NGC 5768 (III 373) in Libra, located 30" of a 13.3 mag star. Although the pair offers nothing spectacular, Herschel was inspired by the impression and compared it with his ‘Fanshaped’, the asymmetric reflection nebula NGC 2245 (IV 3) in Monoceros, found in sweep 81 on 18 January 1784 (Figure 2-26). All ten cases of the ‘brush’ type are listed in Table 2-26 and shown in Figure 2-92.

NGC	H	Sw	Date	Con	V	Type	V*	N	Remarks
296	II 214	268	12 Sep. 1784	Psc	12.6	Gx	9.8	1	nearly edge-on
1253	IV 17	280	20 Sep. 1784	Eri	11.7	Gx	11.6	1	elongated
2245	IV 3	81	18 Jan. 1784	Mon	11.0	RN	7.6	5	‘fanshaped’, sketch Figure 2-26
2261	IV 2	67	26 Dec. 1783	Mon	9.0	RN	12.3	4	Hubble’s Variable Nebula; sketch Figure 2-19
2610	IV 35	503	31 Dec. 1785	Hya	12.7	PN	14.0	1	annular (62"), near 6.6 mag star
3456	IV 29	371	8 Feb. 1785	Crt	12.6	Gx	12.9	3	
3662	IV 4	153	22 Feb. 1784	Leo	12.9	Gx	14.0	2	sketch Figure 2-40
4804	IV 40	548	27 Mar. 1786	Crv	9.8	-	10.4	1	2 stars
4900	I 143	558	30 Apr. 1786	Vir	11.4	Gx	11.0	1	face-on
5768	III 373	400	14 Apr. 1785	Lib	12.5	Gx	13.1	3	barred spiral

Table 2-26: Ten Herschel nebulae, described by him as a ‘brush’ emanating from a star (magnitude V*); the objects are sorted by NGC-number.

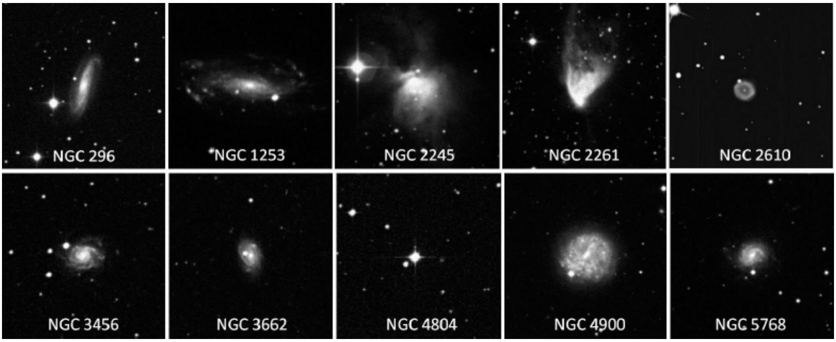


Figure 2-92: The ten objects of Table 2-26. NGC 4804 is only a pair of stars. All images 5' × 5'.

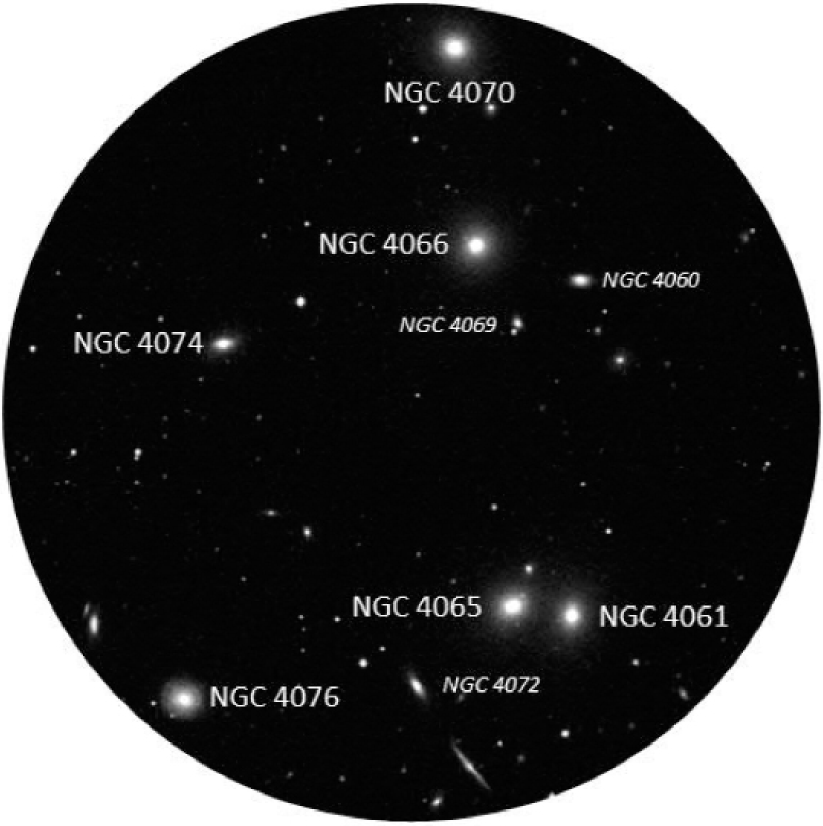


Figure 2-93: Herschel's galaxy sextet in Coma Berenices, found on 26 April 1785 in a single field of view (shown here); three more were perceived, but not catalogued (italics).

On 26 April (sweep 402), a galaxy trio was discovered in Coma Berenices: NGC 4092/95/98 (III 382–84). The 13th mag members form an 8' chain. In the next night (sweep 403), Herschel actually discovered a sextet of nebulae, with a view of three more: "Six, the times and numbers belong to the three first; but I saw three more just south of them. They were all very faint and very small and I suspected many more besides." The six main members of the chain are: NGC 4061 (III 394), NGC 4065 (III 395), NGC 4066 (III 392), NGC 4070 (III 391), NGC 4074 (III 393) and NGC 4076 (III 396). The additional objects, bearing no catalogue designation, are NGC 4060, NGC 4069 and NGC 4072; they have 14.7, 15.2 and 14.8 mag, respectively, which again proves Herschel's exceptional

eyesight.[554] The galaxy sextet was seen again at Slough on 27 December 1786 (sweep 671), now with the 18.7-inch in the front-view mode.

The three additional galaxies of Herschel's sextet in Coma Berenices belong to the eight uncatalogued objects, found in 1785 (not counting NGC 4038 in The Antennae).[555] The first case appeared on 10 March (sweep 382): "Very faint, much brighter middle, pretty large. I partly suspect a very small faint one preceding it about a minute or two, but it may be only a few close very small stars." The main object is NGC 2986 (II 311), a 10.8 mag galaxy in Hydra. The preceding one is the 13.3 mag galaxy MCG -3-25-18 (distance 2.3'). Another uncatalogued object was found on 6 April (sweep 393) in Coma Berenices: "Suspected, but probably a deception of two close stars." This is the 12.9 mag galaxy IC 780. It is Herschel's first IC object, found in a sweep.[556] Then MCG 5-29-24 was discovered in sweep 396 (see section 2.3.3). On 6 October (sweep 459), he encountered the 12.5 mag galaxy NGC 967 in Cetus: "A patch apparently nebulous; but may be only a few stars."

The final uncatalogued objects of 1785 are also located in Cetus, discovered on 27 November (sweep 478) and 30 December (sweep 499). The first is described as: "2 or 3 very small & very close stars; I suspected nebulosity with the sweeping power, but 240 shewed the stars." Actually, Herschel has perceived the 14.4 mag galaxy NGC 17 with its surrounding stars. The second case is the 13.4 mag galaxy MCG -3-5-7: "Suspected but left doubtful, may be very close, very small stars." A special case appeared on 26 September (sweep 442): "Suspected a small irregular patch with seeming nebulosity." Herschel has seen the 12.3 mag galaxy NGC 7469 in Pegasus. However, it had already been discovered on 12 November 1784 (sweep 313) – and catalogued as III 230! His former description reads: "Excessively faint, extremely small, but 240 left no doubt." Unfortunately, in sweep 442, the higher magnification was not applied.

On 1 May, sweep 405 was performed, with 42 objects the one with the second highest yield (after sweep 396 with 71). Herschel observed three remarkable objects. The first, catalogued as IV 30, is described as "2 stars at about 3' distance connected with a very

faint narrow nebulosity.” Although class IV is named ‘planetary nebulae’, it does not refer to the modern term. It mainly contains objects, not fitting in any other class. The strange object is the cometary galaxy NGC 4861 in Canes Venatici. The asymmetric 13.5 mag object has a long tail, starting at a compact nucleus, seen as a ‘star’, and ending at the second (true) star. Shortly after, the 9.8 mag galaxy NGC 5005 (I 96) was discovered in the same constellation: “Very bright, much extended in the parallel. The faint rays included, about 5' long; the bright part of it 1½' long; the brightness decreasing very suddenly.” Then Herschel discovered NGC 5529 (III 414) in Boötes, described as “very much extended”. The edge-on galaxy shows an extreme axis ratio of 9. Only 27' northeast, another remarkable object appeared: NGC 5544 (II 419), described as “faint, pretty large”. Here two galaxies form a physical pair (the second component is NGC 5545); due to a separation of only 28", it was not resolved. A third galaxy was found 17' further west. This is the 11.0 mag galaxy NGC 5557 (I 99); not a remarkable object, but still worth a sketch.[557]

In sweep 406 (2 May), Herschel found a remarkable ensemble in Canes Venatici: “A small patch of stars, seemingly intermixed with nebulosity; but I suppose it to be owing to a few still smaller stars intermixed with them, too faint to be seen.” This is a 2' long chain of four 13–15 mag stars (plus four fainter ones). A similar case was seen on 12 August (sweep 425): “patch or line of very faint stars all in a row, between 2 and 3' long, nearly in the parallel”. This remarkable asterism in western Aquila consists of six 14th mag stars in a line. It is impressive that Herschel has noticed this faint group. Both ‘patches’ are shown in Figure 2-94.

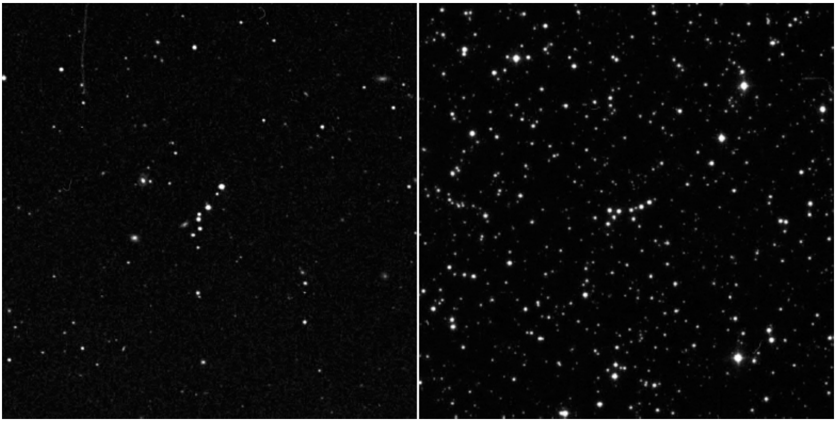


Figure 2-94: Two ‘patches’ found 1785 by Herschel in Canes Venatici (left) and Aquila. Such a nice random star pattern is now called ‘asterism’.

On 28 May, the 18.7-inch reflector got a new mirror, immediately tested in sweep 411: “This evening I had a new beautiful object speculum; it gave very fine images of β Librae, free from all rays and very well concentrated. The polish is very bright, and the figure seems to be better than any I had before.”

With sweep 412 on 30 May at Datchet, a period ended. On 10 June, Herschel wrote in his *Memorandum*: “I left the house at Datchet to remove to a more convenient one at Clay Hall.” The change was necessary because of the problematic environmental conditions at Datchet due to the proximity of the Thames, causing haze and, moreover, dangerous floods.[558] However, Clay Hall, at the eastern edge of the small village Old Winsor, was only 3 km southwest of the former place (Figure 2-95); the river was now about 2 km east – a better choice?

Figure 2-95: Clay Hall near Old Windsor, the next home of the Herschels.[559]

On 10 June, Herschel was ready to observe at the new site; he started sweep 413 at 10:30 pm (nothing was found). Altogether 137 sweeps would follow at Clay Hall until 28 March 1786, when the Herschels moved to their final destination, Slough. After 10 June, there was a period of no less than 27 days until another observation was made. The break may be partly due to bad weather and Full Moon (on the 21st), but Herschel also needed time to install and test new devices: "A time piece of John Shelton's used for the first time; but it is not yet properly fixed nor have I got my time. The degrees as usual determined with the greatest accuracy by the 18-inch Birds quadrant. But all apparatus hardly settled."[560]

On 7 July, Herschel wrote: "A new great rope. Observations on its stretching must be made. The time piece regulated to a few seconds per day, and set by equal altitudes." And on the 17th: "It appears by the quadrant that there has been a variation in the position. The telescope has to day been moved half round so that possibly it may not be so well settled for though I might ascribe the variation to the dew which might perhaps contract the ropes a little; I am rather inclined to believe it wowing to the former cause." In the night (sweep 415), the first object was discovered at Clay Hall: NGC 6823 (VII 18), a remarkable 7.1 mag open cluster in Vulpecula: "An extended cluster of irregularly scattered stars of various sizes, considerably rich; the place taken is that of the brightest part of it; which is towards the south." The compact centre (diameter 36") is

occupied by seven stars of 9.4–11 mag (Figure 2-96). NGC 6823 is located 3.4° west of M 27.

Figure 2-96: The open cluster NGC 6823 in Vulpecula, striking due to its compact centre, was Herschel's first discovery at Clay Hall. The stunning dark feature 4' northwest is part of the surrounding nebula NGC 6820, not perceived by him.

On 12 August (sweep 425), Herschel encountered a close double galaxy in Aquarius (distance 1.8'): "Two, the preceding faint, small, irregularly round, much brighter middle. The following very faint, very small, large brighter middle, about 3 or 4' from the preceding and a little more south. 240 shewed the same." The components are NGC 6962/64 (II 426/27), shining at 12.1 and 13.0 mag. There are four more galaxies in an area of about 12' diameter, fitting in Herschel's field; though having 12–13 mag, they were all missed.[561]

Between the two entries, the sweep record mentions something remarkable about a star, not listed in the *British Catalogue*: “7 m. Bode’s Cat. No. 278 Aquila, De la L, U^{543}.” This refers to the *Uranographia*, a large star atlas plus catalogue, published by Bode in 1801.[562] The Berlin astronomer had taken the star from Lalande’s *Histoire Céleste*. How can it appear in Caroline’s sweep record, describing an observation, made on 12 August 1785? She gives the explanation in the introduction of *Sweep Record No. 1*:

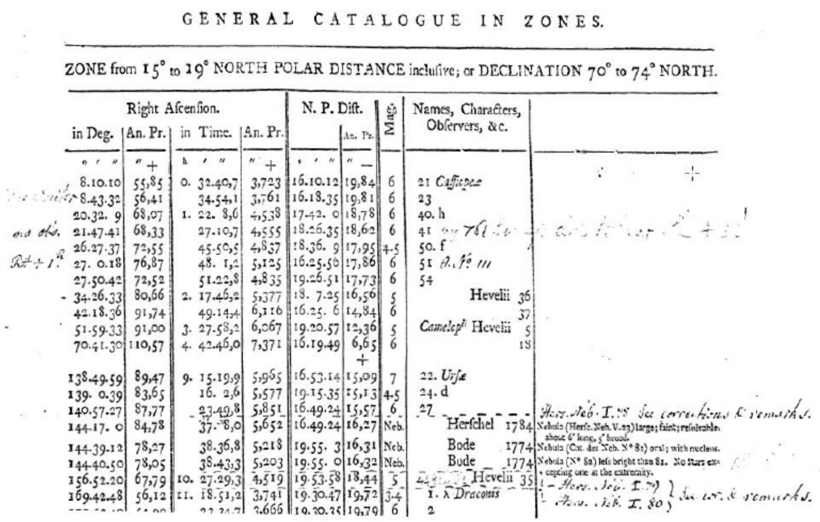
Septr. 1817. When I found the sweeps contained so great a number of unknown stars, I had the idea that when I should have brought all their observations into a catalogue, my brother would have thought it worth while to give them for publication. But by the time I had recalculated the first 424 sweeps and collected 556 unknown stars; we received Bode’s Catalogue; which from that sweep on I began to use jointly with Wollaston’s Catalogue. But I still called such stars as were found in that new acquired catalogue (with the named of later observers than [Tobias] Mayer and La Caille) U; and continued numbering them as unknown; but have added the number it bears in Bode’s Cat. And affixed the name of the observer.

Caroline started the revision of all sweeps (beginning with no. 46) in June 1799 and in September she began to copy the records, though leaving out all sketches; the task was finished on 13 March 1804.[563] In addition to Flamsteed’s standard work, new star catalogues were now on the market or became available in the near future. They offered further reference stars with accurate positions to calculate the coordinates of discovered objects. Moreover, former ‘unknown stars’ (U) could now be identified.

Francis Wollaston was the first to present parts of William Herschel’s work in his publication of 1789, being primarily a revision and extension of Flamsteed’s *British Catalogue*.[564] The important book is titled *A Specimen of a General Astronomical Catalogue, Arranged in Zones of North Polar Distance, and Adapted to Jan. 1, 1790* (Figure 2-97). The subtitle reads ‘Containing a Comparative View of the Mean Positions of Stars, “nebulae” and Clusters of Stars’. Wollaston inserted a selection of objects from Herschel’s first catalogue of nebulae and star clusters, which was

“capable of being discerned with any telescope inferior to his own (i.e. all but his second and third classes; which indeed contain together almost 800)”.565

The arrangement of the data in PD zones exactly met Caroline’s requirements, writing in 1834:566 “At the ending of 1787 or the beginning of 1788 I began to make use of some of the proof sheets of Wollastons Catalogue, along with Flamsteeds.” Because the author was in contact with William and visited Slough in 1786, he probably was inspired by Caroline’s zone catalogue of Flamsteed stars. Alas, the Wollaston’s positions were given for 1790 and she had to precess them to the equinox 1800, used by her. Caroline’s copy of the published catalogue shows an interesting remark on the front page:567 “By order of the Author, I received this Cat. form the publisher gratis.” We find many annotations in the catalogue part (see Figure 2-97).


GENERAL CATALOGUE IN ZONES.

ZONE from 15° to 19° NORTH POLAR DISTANCE inclusive; or DECLINATION 70° to 74° NORTH.

Right Ascension. in Deg.	An. Pr.	in Time.	An. Pr.	N. P. Dist.	An. Pr.	Mag.	Names, Characters, Observers, &c.	
° ′ ″	″ +	h ′ ″	″ +	° ′ ″	″ −			
8.10.10	55,85	0. 32.40,7	3,723	16.10.12	19,84	6	21 *Cassiopeæ*	
8.43.32	56,41	34.54,1	3,761	16.18.35	19,81	6	23	
20.32. 9	68,07	1. 22. 8,6	4,538	17.42. 0	18,78	6	40. h	
21.47.41	68,33	27.10,7	4,555	18.26.35	18,62	6	41	
26.27.37	72,55	45.50,5	4,837	18.36. 9	17,95	4.5	50. f	
27. 0.18	76,87	48. 1,2	5,125	16.25.56	17,86	6	51	
27.50.42	72,52	51.22,8	4,835	19.26.51	17,73	6	54	
34.26.33	80,66	2. 17.46,2	5,377	18. 7.25	16,56	5	Hevelii 36	
42.18.36	91,74	49.14,4	6,116	16.25. 6	14,84	6	37	
51.59.33	91,00	3. 27.58,2	6,067	19.20.57	12,36	5	*Camelop*. Hevelii 5	
70.41.30	110,57	4. 42.46,0	7,371	16.19.49	6,65	6	18	
					+			
138.49.59	89,47	9. 15.19,9	5,965	16.53.14	15,09	7	22. *Ursæ*	
139. 0.39	83,65	16. 2,6	5,577	19.15.35	15,13	4.5	24. d	
140.57.27	87,77	23.49,8	5,851	16.49.24	15,57	6	27	
144.17. 0	84,78	37. 8,0	5,652	16.49.24	16,27	Neb.	Herschel 1784	Nebula (Hersc. Neb. V. 23) large; faint; resolvable, about 6′ long, 5′ broad.
144.39.12	78,27	38.36,8	5,218	19.55. 3	16,31	Neb.	Bode 1774	Nebula (Cat. des Neb. N° 81) oval; with nucleus.
144.40.50	78,05	38.43,3	5,203	19.55. 0	16,32	Neb.	Bode 1774	Nebula (N° 82) less bright than 81. No stars excepting one at the extremity.
156.52.20	67,79	10. 27.29,3	4,519	19.53.58	18,44	5	Hevelii 35	
169.42.48	56,12	11. 18.51,2	3,741	19.30.47	19,72	3.4	1. λ *Draconis*	
[illegible]	[illegible]	22.24,7	3,666	19.30.35	19,79	6	2	

Figure 2-97: Francis Wollaston’s zonal star catalogue of 1789 also contains Messier objects and a selection of Herschel’s non-stellar objects and double stars (Caroline’s copy with annotations).

Caroline noticed that Wollaston’s Flamsteed numbers for Lynx are partly different from William’s. Her brother had counted the entry following no. 34 as no. 35, although, due to an error by Flamsteed, the row was erased in the printed catalogue. Alas, the number “7”

(magnitude) was left, which probably had irritated William. Thus, the 10 Lynx stars from no. 36 on must have a number reduced by one: 36 Lyn → 35 Lyn to 45 Lyn → 44 Lyn (Figure 2-98).[568] This error has led to wrong positions for some objects.

								H	W
AdEductionemCaudæ præcedens	124 53 0	43 7 30	25 53 57	26 29 5	76 15	13 28	6	34	34
							7	35	-
AdEductioneimCaudæfequens	127 44 10	45 10 10	28 37. 20	25 1 55	74 3	14 25	6	36	35

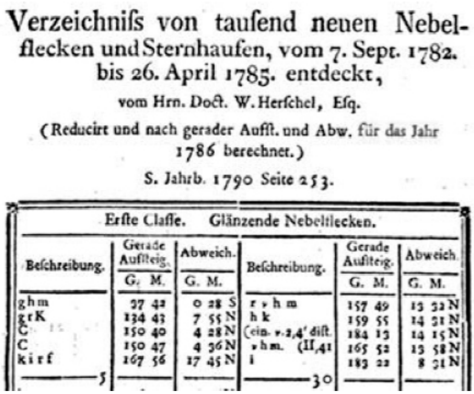
Figure 2-98: The ‘Lynx error’: Herschel’s (H) wrong numbering in Lynx, corrected by Wollaston (W); see text.

7 Camelodardalis Hevelii was the first star, taken from the mentioned proof sheets; it was used on 1 November 1788 in the northern sweep 878. From this date on, all positions in the Carline’s ‘Original’ are given for 1790. William could now sweep northern regions, where no Flamsteed stars are available.

In 1801, Caroline received Bode’s atlas and catalogue. It would become the major source for her sweep revision. She later wrote:[569] “In June 1799 began (when no other work in hand) to recalculating sweeps, I had as far as the 387 sweep and a Cat. of Stars which I then supposed as unknown amounted to 514 when Sept. 24, 1801, Bode’s Cat came first in my hands I was by this acquisition brought into some confusion and if there had been time for calculating the 387 sw. over again the beginning would not have been as over crouded etc.” Caroline first used the important source on 8 November 1801 in sweeps 1100 & 1101 and applied the new equinox (1801).

Johann Elert Bode (Figure 2-99) was a diligent observer, always interested in non-stellar objects. Competitors inspired him – and with the *Berliner Jahrbuch*, edited by him, he had a medium to disseminate his results. In 1777, shortly after the first *Messier Catalogue* of 45 objects had appeared, he published a list of 75 new nebulae. His atlas and star catalogue *Vorstellung der Gestirne* of 1782 also featured them (figures of each object are added).[570] The Berlin astronomer admired Herschel and was the first to print German versions of the three catalogues in his popular almanac, though each with a respectful delay of two years (Figure 2-99).[571] His aim was not a new reduction of the data, but to make the important

work accessible to German-speaking readers. Bode kept the original order of the entries but translated the coded descriptions to get an even more compact version. Coordinates were calculated from the relative positions (to the reference stars) for 1786, 1790 and 1801, respectively.



Verzeichniſs von tauſend neuen Nebelflecken und Sternhaufen, vom 7. Sept. 1782. bis 26. April 1785. entdeckt,

vom Hrn. Doct. W. Herſchel, Eſq.

(Reducirt und nach gerader Aufſt. und Abw. für das Jahr 1786 berechnet.)

S. Jahrb. 1790 Seite 253.

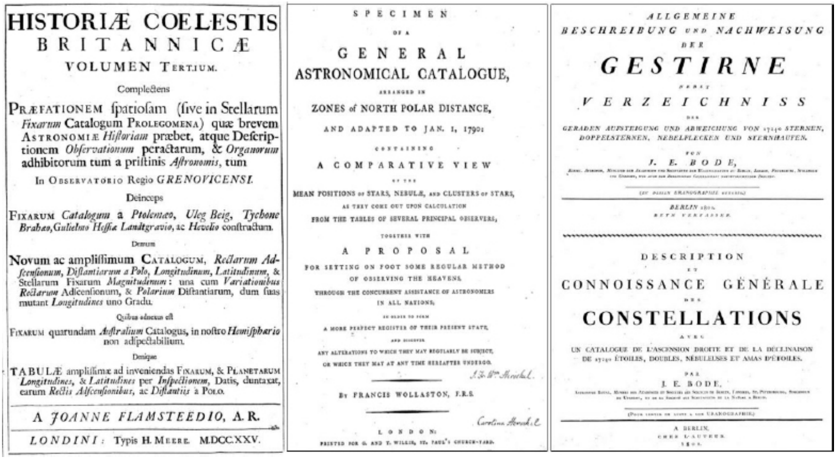
Erſte Claſſe. Glänzende Nebelflecken.

Beſchreibung.	Gerade Aufſteig. G. M.	Abweich. G. M.	Beſchreibung.	Gerade Aufſteig. G. M.	Abweich. G. M.
g h m	37 42	0 28 S	r v h m	157 49	13 32 N
g r K	134 43	7 55 N	h k	159 55	14 31 N
C	150 40	4 28 N	(ein. v. 2,4' diſt.	184 13	14 15 N
C	150 47	4 36 N	v h m. (II,41	165 52	13 58 N
k i r f	167 56	17 45 N	i	183 22	8 31 N
5			30		

Figure 2-99: Johann Elert Bode and his German version of Herschel's first catalogue, published in 1788. The table shows the description and coordinates (α and δ in degrees) for 1786.

The content of Herschel's first and second nebular catalogues and his two double star catalogues also appeared in Bode's monumental *Uranographia* of 1801. The work consists of a large-scale atlas plus a catalogue of 17,240 stars, double stars, nebulae and stars clusters.[572] Heinrich d'Arrest and Arthur Auwers later criticized his version of the Herschel catalogues; the former wrote:[573] "Even if one ignores the inaccurate star positions, used to determine the coordinates of the nebulae, the work is distorted by many errors." For instance, the position of I 1 (NGC 1055) deviates from Herschel's (which is fine) by about 11'.

Figure 2-100 shows the title pages of the three fundamental star catalogues, used by Caroline: Flamsteed's *British Catalogue* and its major successors, made by Wollaston and Bode.


HISTORIÆ COELESTIS BRITANNICÆ
VOLUMEN TERTIUM.
Complectens
PRÆFATIONEM spatiosam (sive in Stellarum Fixarum Catalogum PROLEGOMENA) quæ brevem ASTRONOMIÆ Historiam præbet, atque Descriptionem Observationum peractarum, & Organorum adhibitorum tum a pristinis Astronomis, tum
In OBSERVATORIO Regio GRENOVICENSI.
Deinceps
FIXARUM Catalogum a Ptolemæo, Uleg Beig, Tychone Brahæo, Gulielmo Hassiæ Landtgravio, ac Hevelio constructum.
Deinum
Novum ac amplissimum CATALOGUM, Rectarum Adscensionum, Distantiarum a Polo, Longitudinum, Latitudinum, & Stellarum Fixarum Magnitudinum: una cum Variationibus Rectarum Adscensionum, & Polarium Distantiarum, dum suas mutant Longitudines uno Gradu.
Quibus adnexus est
FIXARUM quarundam Australium Catalogus, in nostro Hemisphærio non adspectabilium.
Denique
TABULÆ amplissimæ ad inveniendas FIXARUM, & PLANETARUM Longitudines, & Latitudines per Inspectionem, Datis, duntaxat, earum Rectis Adscensionibus, ac Distantiis à POLO.
A JOANNE FLAMSTEEDIO, A.R.
LONDINI: Typis H. MEERE. MDCCXXV.

SPECIMEN
OF A
GENERAL
ASTRONOMICAL CATALOGUE,
ARRANGED IN
ZONES of NORTH POLAR DISTANCE,
AND ADAPTED TO JAN. 1, 1790:
CONTAINING
A COMPARATIVE VIEW
OF THE
MEAN POSITIONS OF STARS, NEBULÆ, AND CLUSTERS OF STARS,
AS THEY COME OUT UPON CALCULATION
FROM THE TABLES OF SEVERAL PRINCIPAL OBSERVERS;
TOGETHER WITH
A PROPOSAL
FOR SETTING ON FOOT SOME REGULAR METHOD
OF OBSERVING THE HEAVENS,
THROUGH THE CONCURRENT ASSISTANCE OF ASTRONOMERS
IN ALL NATIONS;
IN ORDER TO FORM
A MORE PERFECT REGISTER OF THEIR PRESENT STATE,
AND DISCOVER
ANY ALTERATIONS TO WHICH THEY MAY REGULARLY BE SUBJECT,
OR WHICH THEY MAY AT ANY TIME HEREAFTER UNDERGO.
BY FRANCIS WOLLASTON, F.R.S.
Caroline Herschel
LONDON:
PRINTED FOR G. AND T. WILKIE, ST. PAUL'S CHURCH-YARD.

ALLGEMEINE
BESCHREIBUNG UND NACHWEISUNG
DER
GESTIRNE
NEBST
VERZEICHNISS
DER
GERADEN AUFSTEIGUNG UND ABWEICHUNG VON 17240 STERNEN, DOPPELSTERNEN, NEBELFLECKEN UND STERNHAUFEN.
VON
J. E. BODE,
BERLIN 1801.
BEYM VERFASSER.

DESCRIPTION
ET
CONNOISSANCE GÉNÉRALE
DES
CONSTELLATIONS
AVEC
UN CATALOGUE DE L'ASCENSION DROITE ET DE LA DÉCLINAISON DE 17240 ÉTOILES, DOUBLES, NÉBULEUSES ET AMAS D'ÉTOILES.
PAR
J. E. BODE,
A BERLIN,
CHEZ L'AUTEUR.
1801.

Figure 2-100: Three important star catalogues, used by Caroline over the years (left to right): John Flamsteed's *British Catalogue* (1725), Francis Wollaston's revision (1789) and Johann Elert Bode's star catalogue (1801).

Back to 1785. On 10 September (sweep 435), Herschel found the galaxies NGC 584/86 (I 100/III 431) in Cetus with 10.5 and 13.2 mag (distance 4.2'); both were seen in a single field. The following detail is interesting: 41 Cet is given as reference star for I 100, but for III 431 we read "Neb. I. 100" in the column 'Stars'. Table 2-27 lists similar cases, but also some strange ones. The 13.4 mag galaxy NGC 6301 (IV 57) was referenced in sweep 746 by the globular cluster M 92; in a second observation (sweep 831, 12 April 1788), the star σ Her was used. The latter was entered in the second catalogue. In sweep 1030, M 38 was not only used for the emission nebula I 261 (NGC 1931) but also for VII 39 (NGC 1611), a mix of nebula and cluster, and finally for M 36. In the second catalogue, VII 39 is referenced by σ Her; this belongs to the observation in sweep 693 (17 January 1787), when the object was discovered. In the revised sweep records, Caroline used stars from Bode's catalogue in sweeps 842, 927 and 1030.

Cat	H	'Reference star'	Sw	Object	NGC	V	Con	Dates
1	II 18	I. Class 7 Neb.	105	M 49	4472	8.3	Vir	23 Jan. 1784
2	III 431	Neb. I. 100	435	I 100	584	10.5	Cet	10 Sep. 1785
2	IV 57	35 (σ) Hercul	746	M 92	6341	6.5	Her	11 Jun. 1787
2	II 745, III 723	Neb. II 728	822	II 728	3583	11.1	UMa	1 Apr. 1788
2	II 758-62	Neb. II 757	842	II 757	5879	11.6	Dra	5 May 1788
3	II 808	Neb. II. 756	927	II 756	5820	12.5	Boo	24 Apr. 1789
3	I 261	38 of the	1030	M 38	1912	6.4	Aur	4 Feb. 1793
3	III 937	Neb. I 274	1064	I 274	4648	12.0	Dra	22 Nov. 1797
3	I 273, III 938	A double star	1066	N118	-	8.0	Dra	10 Dec. 1797
3	III 898, III 934, I 272	Georgian planet	-	Uranus	-	5.4	Leo	22 Mar. & 1 Apr. 1794, 4 Mar. 1796

Table 2-27: Unusual 'reference stars', used for relative positions of objects (H) in the three Herschel catalogues (Cat); 'Reference star' shows the original entry, 'Object' gives its identity (followed by NGC-number and data).

8° southeast of Markab (α Peg), at the border to Pisces, the Pegasus I Cluster was crossed on 30 August (sweep 427) and 26 September (sweep 442). The NGC lists 19 galaxies, of which Herschel discovered six in the two sweeps (Table 2-25). In the first (427), the close pair NGC 7537/41 (II 429/30) was found; the galaxies are 3' apart. Herschel wrote: "Two, the time and number is that of the largest. Much extended, about 4' long, pretty bright extendedly much brighter middle, about 1' broad, the extent nearly in the parallel. The other is very faint, considerably small, about 3 or 4' south preceding the large one; and but for the large one might have been overlooked." In sweep 442, he saw four members: NGC 7619 (II 439, 11.1 mag), NGC 7623 (III 435, 12.9 mag), NGC 7626 (II 440, 11.1 mag) and NGC 7634 (II 441, 12.6 mag).574

An important new device was installed on 24 September (sweep 440), the 'PD clock': "This evening I used a new Polar distance machine contrived so as to shew the polar distance of the tube in every situation. At the beginning of a sweep the machine is set to the PD of the zero and it ought afterwards to go always right. In the sweep, however, the setting part not being finished, it has been suffered to shew wrong and the correction to be applied to the machine are pointed out in the calculation." By the 'polar distance machine', the actual PD was directly available at Caroline's desk. The PD index, which must be transformed into a coordinate, became obsolete. In Caroline's *Sweeps No. 4* we now see a column giving the PD. This implied another innovation (see heading of sweep 440): "By the Present time & PD". From now on, Caroline reduced the positions of Flamsteed stars to the equinox of the date

(1785). The change, already announced at the end of 1784 (for the following year), was now realized. The first star is Altair (α Aql): Caroline added the precession to the 1690 position. This was done by two multipliers, written down for 1783 on the last page of *Sweeps No. 3*: “Multiplier for 1783 in Variation. 1’ = 1’,2917 in PD in space. 1” = 0",0861 in AR in time.” The values are 93/72 and 93/(72·15); for 1785 she used 95 instead of 93. Applied to the 72-year precession of the *British Catalogue*, the correct values were calculated.

On 1 October (sweep 448), Herschel discovered a very close pair in Cetus: NGC 545/47 (II 448/49), the distance is only 30" (Table 2-28 and Figure 2-101). He wrote: “Two, stellar of equal size; and within a minute of each other. Their nebulosities run together and at first sight seem to form only one extended nebula.” The two 12.2 mag galaxies form the closest pair, Herschel has ever seen. They are located in the centre of the galaxy cluster Abell 194 (Table 2-25). In the sweep, he discovered two other members: NGC 560 and NGC 564 (III 441/42), with 13.0 and 12.5 mag.575 The 3rd (sweep 450) brought another close pair: NGC 7443/44 (II 450/51) in Aquarius; the 12.9 and 11.6 mag galaxies are only 1.6' apart: “Two, both a little extended and about 1½' from each other, they extend in different directions. The sweeping power shewed but one, but 240 distinguished them both, and I saw them afterwards also both with the former power. Both very faint, very small.”

Dist (")	NGC1	H1	V1	NGC2	H2	V2	Con	Sw	Date	Remarks
30	545	II 448	12.2	547	II 449	12.2	Cet	448	1 Oct. 1785	in Abell 194
40	1633	III 952	13.5	1634	III 953	14.1	Tau	1085	12 Sep. 1798	
41	4782	I 135	11.7	4783	I 136	11.6	Crv	548	27 Mar. 1786	NGC 4794 (III 538) 9' SE
46	5953	II 178	12.3	5954	II 179	12.2	Ser	200	17 Apr. 1784	
49	741	II 271	11.1	742	II 272	14.3	Psc	338	13 Dec. 1784	NGC 742 has a high surface brightness
50	2802	III 62	14.3	2803	III 63	14.0	Cnc	181	21 Mar. 1784	
52	4403	III 755	12.8	4404	III 756	12.7	Vir	913	20 Mar. 1789	
52	4496	II 36	11.4	4505	III 18	13.9	Vir	158	23 Feb. 1784	
54	4724	III 280	12.7	4727	II 298	11.8	Crv	372	8 Feb. 1785	
56	1587	II 8	11.7	1588	II 9	12.9	Tau	54	19 Dec. 1783	first pair; NGC 1589 (II 7) 12' N
58	833	II 482	12.7	835	II 483	12.1	Cet	479	28 Nov. 1785	group with NGC 838/39 (III 484/85)
59	5851	III 886	14.1	5852	III 887	13.6	Boo	1011	26 May 1791	
59	7805	III 855	13.3	7806	III 856	13.5	Peg	971	9 Oct. 1790	

Table 2-28: The closest double galaxies (distance < 60"), discovered by Herschel in a single field.

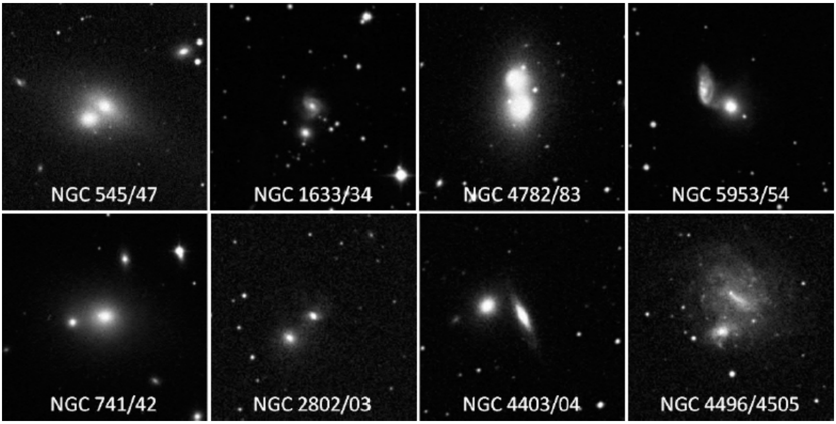


Figure 2-101: The six closest double galaxies of Table 2-28; all images 5' × 5'.

In sweep 459 (6 October), Herschel found two galaxies in Eridanus with 12.0 and 9.7 mag: NGC 1393 (III 451) and NGC 1407 (I 107). The brighter was sketched (Figure 2-102). They belong to a group of eight NGC galaxies within 1°. A third member, the 11.0 mag galaxy NGC 1400 (II 593), was found on 20 September 1786 (sweep 597).

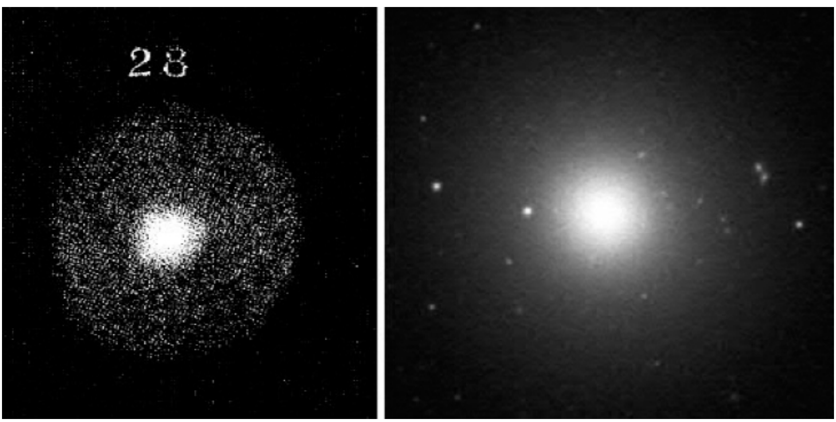


Figure 2-102: The 9.7 mag galaxy NGC 1407 in Eridanus was discovered on 6 October 1785.

On 26 October (sweep 465), Herschel encountered a 12.1 mag double galaxy, which was too close for him to resolve (30"): NGC

7284 (II 469) in Aquarius. He wrote: "Faint, easily resolvable or some of the stars visible; a little extended, pretty small." The object followed the peculiar 11.4 mag galaxy NGC 7252 (III 458) by 1.8°, described as "very faint, small, easily resolvable, 240 confirmed it with difficulty." The sweep also brought the planetary nebula NGC 6629 (II 204) in Sagittarius ("I suspected a pretty bright stellar nebula np a pretty bright star, but there was too much daylight to verify it."); the nebula has 11.3 mag, the 12.8 mag central star was not seen.

On 1 November 1785, Herschel had a guest at Clay Hall, who was allowed to sweep with the 20-ft. It was John Smeaton.[576] We read: "Partly Mr. Smeatons observation." When the guest was sufficiently instructed and placed in the observer chair, the sweep started at 0:50 am. It was made in Eridanus and lasted only 40 minutes; Caroline marked the sweep as "not to be numbered or registered". Fortunately, we have Smeaton's report, due to a letter wrote on the 4th to John Mitchell.[577] Curiously, Herschel is called 'Herschall' or 'Hirschall'. Here is the part of the text which concern important technical and observational aspects:

With this Telescope, he is now and has been for some time past at work, as he calls it, sweeping the Heavens. The whole Apparatus can upon occasion be turned to any Azimuth; but is chiefly used, the Telescope turning in the plain of the Meridian. The butt end, or great Speculum end of the Tube, is supported immediately upon the Ground; the other end of the Tube, is raised & lowered by a Tackle, supported at top upon a double equilateral Triangle (or thereabouts). The Observer is also hoisted up in a Chair, that rocks on Rollers upon the inclined Legs of the Triangle next the Eye Glass; and the Eye Glass is brought to answer to this straight line, by sliding the butt of the Telescope nearer the Centre of the whole Machine; and by the same means it can be put into a vertical Position. The raising the Chair and the sliding of the Butt are done by separate Tackles respectively; touched only occasionally; but the main Tackle that raises the Telescope when brought to its intended Elevation, that is polar distance, is worked by a distinct motion; that causes it to rise and fall alternately, through a space of 2 degrees of the Meridian; which being done with some degree of briskness; a fillet in the heavens is Examined at once of 2 degrees

broad; the motion of the heavens in AR bringing on the Objects in Succession. By way of Register, large sheets of Paper are prepared, marked & numbered; being ruled into parallel lines, cross and cross, and about ¼ inch distance; a small square of this kind representing ¼ of a degree in AR and declination. All those that are examined are marked with a cross, and those that have been seen, but not fully examined, with a stroke one way; and when afterwards seen to satisfaction, the cross is completed; the place and species of the object is also marked upon the Paper. In this Operation three persons are Concerned; a Labourer works continually the handle backwards & forwards, for performing the destined range; and in this he is prevented from ranging too little, or too much, by a small piece of Machinery that strikes a Bell, at each end of the Range; he also stops on notice; and if any thing comes requiring this notice, and the Object to be pursued, the telescope can, by an Apparatus which occasionally heaves it from its meridian bearing, pursue it in right Ascension for near a quarter of an hour. And that there may be no need for the Observers Eye to be taken from the Eye Glass; an Assistant (Mr Herschall's Sister) situate in an adjacent Room with the squared sheet before her, upon it notes down, and in a book writes down what is dictated. The Time she has from the Clock before her; and the polar distance by a piece of Machinery, which continually shews the degree and minutes; and is worked by a string actuated by the Telescope, in rising and falling; comes into the room, & winding round a small Barrel, performs the requisite Motions. The Telescope is set to its altitude by a small Quadrant, fixed upon it; & the Corresponding index is regulated answerable to the stretching of the cord of communication, by observing the first known Star that passes of Flamsteeds Catalogue. By this means what has been done, & what is to do, is distinctly seen by the Sheets. In this way many hundred of Nebulas have been discovered, not only unknown before, but which no ordinary Telescopes will reach.

The text describes interesting technical and methodical features: observing chair (on rollers), bar and bell mechanisms ("a small piece of Machinery that strikes the Bell") and quadrant. Caroline's 'Register of Sweeps according to the time of observation'[578] is described (Figure 2-103): "large sheets of Paper are prepared, marked & numbered; being ruled into parallel lines, cross and cross,

and about ¼ inch distance; a small square of this kind representing ¼ of a degree in AR and declination”.[579] Smeaton speaks of three persons, but only two are mentioned: “a Labourer” (workman) and “an Assistant” (Caroline); the third must be the observer. He further speaks of “stops on notice” and object tracking “for near a quarter of an hour”. This equals 15 fields of view at the equator – much more than the ‘side motion’ allows; the statement is thus questionable. The night continued at 2:20 am with Herschel’s sweep 468, made in Orion and Monoceros. It terminated with the open cluster M 50.

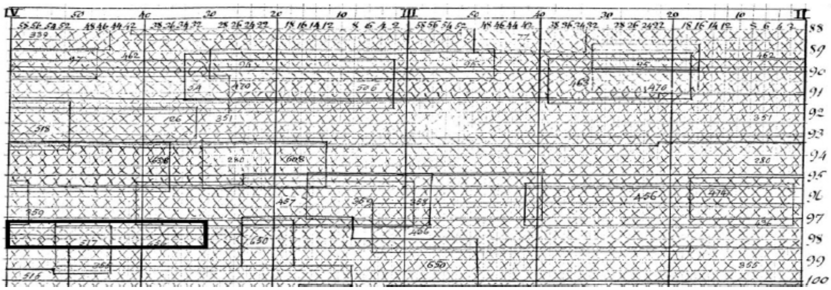


Figure 2-103: Caroline’s ‘Register of Sweeps’, described by Smeaton while at Clay Hall on 1 November 1785. The rectangular region in Eridanus, swept that night by the visitor is marked; Herschel later covered it in sweeps 517 and 656.

On 28 November (sweep 479), a remarkable quartet was found in Cetus. The four galaxies, known as NGC 833/35/38/39, roughly form a chain of 6' length. Herschel noted: “Two, both faint, both extended and small, within a minute of each other, and not far from the parallel. This pair (NGC 833/35), distance 57", is among the closest, he has ever seen (see Table 2-28). “About 4 or 5' south and about 2" [seconds] following are to more, a little fainter and smaller; both also extended and resembling each other, about 2' from each other, and the situation not far from the meridian. 240 verified them all, so as to leave no doubt.” He rested about two minutes at the quartet: “A short stop occasioned by looking at the four nebulae, probably I missed some by it.” The galaxies are of 12.1 to 13.1 mag and were catalogued as II 482–85.[580] Herschel’s four galaxy quartets are listed in Table 2-29 and shown in Figure 2-104.

NGC1	H1	V1	NGC2	H2	V2	NGC3	H3	V3	NGC4	H4	V4	Con	Sw	Date
4169	III 358	12.2	4173	II 372	13.0	4174	III 359	13.4	4175	III 360	13.3	Com	396	11 Apr 1785
833	II 482	12.7	835	II 483	12.1	838	II 484	13.0	839	II 485	13.1	Cet	479	28 Nov. 1785
4268	II 568	12.8	4270	II 569	12.2	4273	II 570	11.9	4281	II 571	11.3	Vir	553	17 Apr. 1786
703	III 562	13.3	704	III 563	12.8	705	III 564	13.6	708	III 565	12.7	And	599	21 Sep. 1786

Table 2-29: Herschel found four galaxy quartets; the first and most prominent is The Box in Coma Berenices, seen in sweep 396 (all are presented in Figure 2-104). The last lies in the centre of the galaxy cluster Abell 262 in Andromeda.

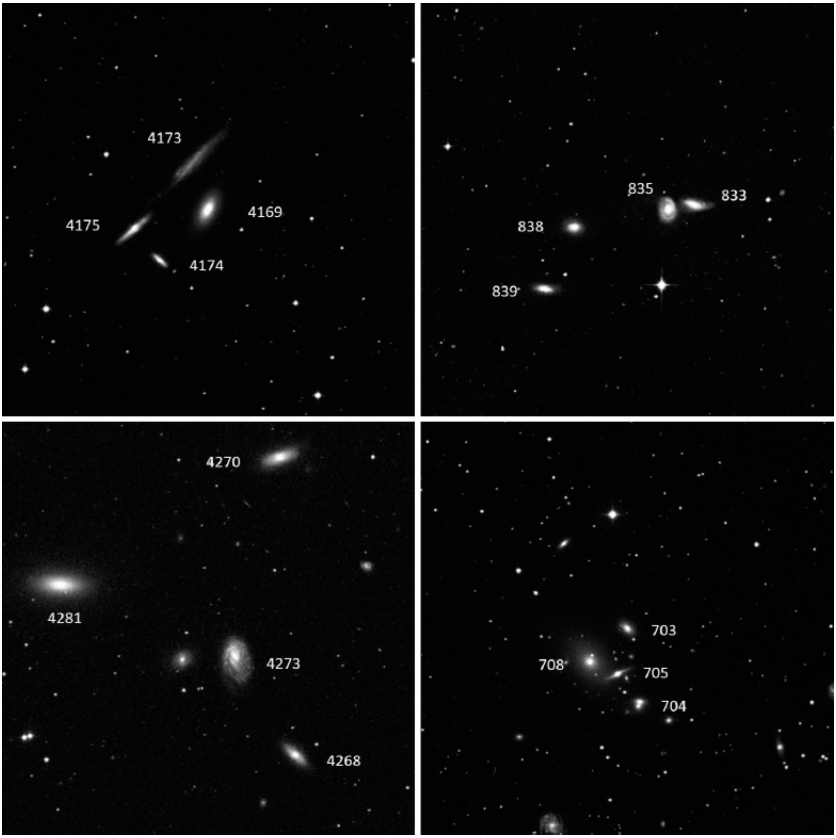


Figure 2-104: Herschel's four galaxy quartets, seen in a single field of view (see Table 2-29); all images 15' × 15'.

In sweep 484 on 5 December, Herschel discovered the 12.7 mag galaxy NGC 160 (III 476) in Andromeda: "Very faint, very small, stellar, a few minutes of a pretty bright star, 240 shewed the same." The 7.2 mag star is only 4.2' northeast. However, he missed

another, and even brighter galaxy, NGC 169, only 11' east and 12.4 mag bright.[581] Alas, the sweep path did not allow this view.

December brought a pair and a trio of galaxies and a curious ‘double cluster’. On the 7th (sweep 487), Herschel saw NGC 3395/96 (I 116/17) in Leo Minor; the 12th mag galaxies are only 1.3' apart. He noted: “Two, the 1st considerably bright, the 2nd pretty bright, the 1st considerably large, the 2nd pretty large, both a little and irregularly extended, their extent makes an angle, the vertex of which is towards the north, about 1' from each other at the vertex.” The trio was found in the same sweep: NGC 3413/24/30 (II 493, II 494, I 118) in Leo Minor. They form a galaxy chain of 15' length from southwest to northeast. With 11.6 mag, NGC 3430 is the brightest member (the galaxy is not listed in the *Zone Catalogue*).

The ‘double cluster’ was found on 26 December (sweep 493) in Taurus; the centres of the open clusters are only 13' apart. The unusual pair is NGC 1750 (VIII 43) and NGC 1758 (VI 41). Herschel wrote for NGC 1750: “A cluster of very coarsely scattered small stars, joining to the following I believe.” The “following” is “A cluster of pretty compressed stars with many extremely small mixed with them.” NGC 1750/58 are nearby in space, but actually separate objects (Figure 2-105).[582] This is one of only two cases where Herschel found a pair of non-stellar objects, in which both partners are not galaxies. The other is NGC 6939 (open cluster) and NGC 6946 (galaxy) in Cepheus, found on 9 September 1798 (sweep 1077) in Cepheus (see Figure 3-8).

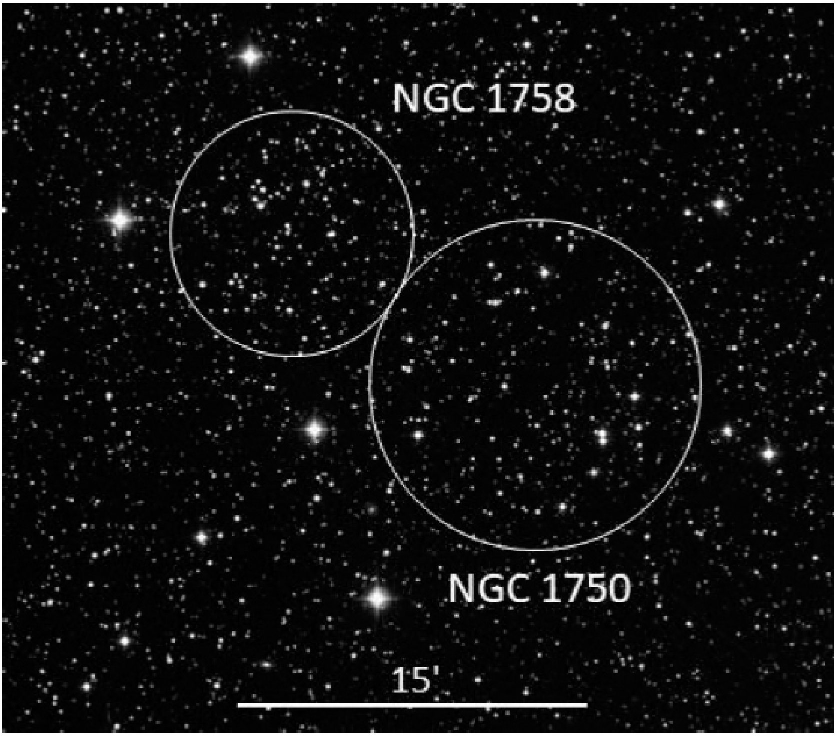


Figure 2-105: NGC 1750 and NGC 1758 in Taurus, found on 26 December 1785, is a unique (optical) pair of open clusters.

In sweep 496 on 28 December, Herschel found "A very coarsely scattered cluster of large stars, they form a cross and extended over a large space; not rich". The object, NGC 2394 (VIII 44), is located 3° northwest of Procyon. This would just be a barely noteworthy star group if there wasn't a sketch. In the same night (sweep 498), another sketch was made, showing an extended object. This is the 10.0 mag galaxy NGC 4535 (II 500) in Virgo. The presentation is neither supported by the description ("very large, easily resolvable, I see a few of the largest of the stars") nor by the face-on view of the barred spiral galaxy. Both sketches are seen in Figure 2-106.

On New Year's Eve (sweep 503), a remarkable planetary nebula was found: NGC 2610 (IV 35) in Hydra: "A small star with an electric brush south preceding. Faint, small, about 1½' after follows a star of the 8th magnitude, it resembles figure 7, Phils. Trans. Vol. 74, Tab. 17." The object was sketched (see Table 2-26 and Figure 2-92). The

reference points to the cometary nebula NGC 2261 (IV 2) in Monoceros, discovered and sketched on 26 December 1783 in sweep 67 (see Table 2-8). Later, the 11.8 mag galaxy NGC 2848 (III 488) in Hydra was found; a sketch was made.[583] The night also brought a galaxy group in Virgo, consisting of four galaxies within 30': NGC 5037/44/49/54 (II 510–513). With 10.8 and 10.9 mag, NGC 5044 and NGC 5054 are the brightest members; the other two are fainter (12.2 and 13.0 mag). These were the last objects, discovered in 1785.[584]

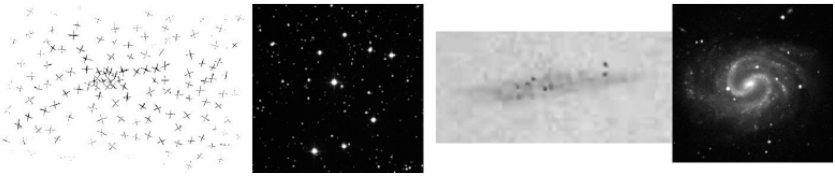


Figure 2-106: Two objects, found on 28 December 1785. Left: NGC 2394 in Canis Minor, a star group 3° northwest of Procyon; right: the face-on galaxy NGC 4535 in Virgo (not really represented by the sketch).

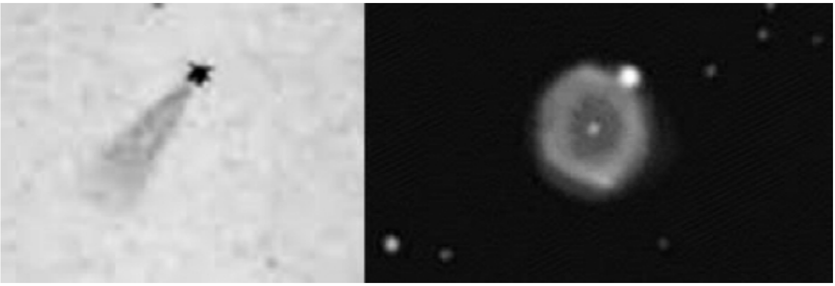


Figure 2-107: The 12.9 mag planetary nebula NGC 2610 in Hydra, found on 31 December 1785, seen as star with a 'brush'.

2.3.5. Messier objects and a 'demonstration sweep'

19 different Messier objects were observed in 1785. Only one was new, the open cluster M 50 in Monoceros, long known from Ferguson's *Astronomy*. It was seen with the 20-ft in sweep 377 on 4 March: "A very brilliant cluster of scattered large stars, considerably compressed and rich, above 20' in diameter. The stars of various sizes; visible in the finder." In this sweep, two open clusters, NGC

2302 (VIII 39) and NGC 2309 (VI 18), and an emission nebula, NGC 2316 (II 304), were discovered. Because the *British Catalogue* offered no reference star, Herschel took M 50 (1° southeast): “The sweep determined by the 50th cluster of stars of the Connoissance des Temps.” It was also used for the three ‘unknown stars’ (U^{472}, U^{473}, U^{474}). However, for M 50 itself we read that the position was calculated “by 11 Monocerotis in … Sw.” Indeed, in the first catalogue VIII 39, VI 18 and II 304 are referenced to 11 Mon. But where does the star position comes from? We find it in sweep 468, made on 1 November 1785.[585] Both 11 Mon and M 50 were observed; the reference star is 8.5° east of the open cluster. Often times, positions in Caroline’s records were left as relative measurements until they could be fixed in a later sweep.

Five Messier objects were seen for the first time in the 20-ft: M 5, M 12, M 35, M 47, M 62. M 47 was seen on 4 February (sweep 366), but not identified as a Messier object. Herschel catalogued it as VII 38: “A very coarsely scattered cluster of several stars very large and other different sized stars.” On the 28th (sweep 374), he viewed M 35: “A very large cluster of considerably large stars pretty compressed.” The object did not fit into the field of view. The globular cluster M 12 was seen on 14 April in sweep 400: “A brilliant cluster of stars completely visible, very much condensed in the center; the stragling of stars that seem to belong to it extend to 7, 8 or 9' diameter.” M 5 followed on 5 May (sweep 409):

A very compressed very beautiful and large cluster of small stars of various sizes, and of a red colour. For about 2 or 2½' they are extremely compressed in the center; and the pretty regularly scattered stars extend to about 7 or 8' diameter. Then there are besides many more irregularly scattered at a greater distance; especially one branch, which extends in a direction of about 15 or 30 degrees south preceding and some of the stars of this branch are rather larger than the rest. It is the 5th of the Conn. des temps. My sister also saw it in the same manner.

Because the globular cluster had an altitude of 40°, the chair was about 3.5 m above the ground – a dangerous position to change the observer. Obviously, brave Caroline has managed the task.

In the next night (6 May), Herschel performed a ‘demonstration

sweep', which was not counted. It may be called '409a', as sweep 409 is dated 5 May.[586] Herschel had three helpers, performing different observations: Count de Brühl, Alexander Aubert and Franz Xaver von Zach.[587] The observing session started at 9:30 pm in Virgo. Herschel wrote: "A nebula. Count de Brühl." However, it was not new, since Caroline later added: "No. 58 of the Connoissance des temps is nearly in the place." Indeed, the 9.6 mag galaxy M 58 in Virgo was seen. After a break of two hours, the globular cluster M 5 in Serpens was observed at 0:10 am. Herschel wrote: "Count Brühl, Mr. Aubert and Mr. Zach saw the 5th Nebuleuse sans étoiles of the Connoiss. and found it as described in the 409 sweep. Except the colour of the stars to which they had not attended; nor indeed (not being acquainted with my method of estimating) could they assign the extent of the phenomena in minutes." Then three star gages were made in Serpens. In the first and third, Aubert was at the eye-piece, the second was performed by Herschel himself. Afterwards, v. Zach took over, observing the star σ Ser. Then Herschel measured λ Oph, followed by another star gage by Aubert. Finally, Count de Brühl observed 21 Oph. The sweep ended at 1:40 am. The three visitors had to climb the right front ladder to reach the observing chair at the Newtonian focus, about 3.5 m above the ground. For unexperienced people, this action in the dark was a challenge.

The globular cluster M 62 the Ophiuchus/Scorpius border was seen on 11 May in sweep 410: "Resolvable or a miniature of the 3rd [M 3]. I see several of the stars. About 5' diameter, much brighter middle and the brightness diminishing very gradually all the way." M 2, the globular cluster in Aquarius, and the Black Eye Galaxy M 64 in Coma Berenice were viewed three times in 1785.

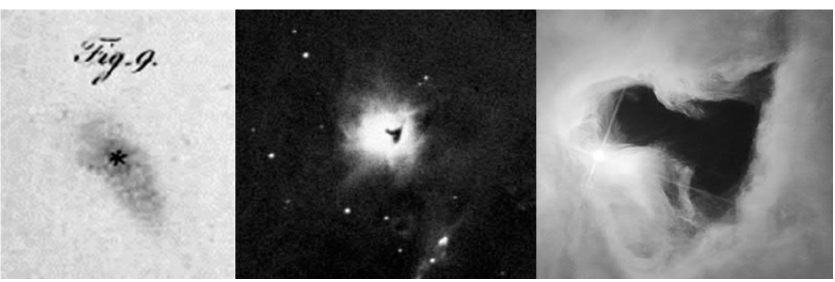


Figure 2-108: The emission nebula NGC 1999 in Orion was

discovered on 5 October 1785. Herschel's sketch was made on 24 February 1786; it does not show the tiny dark structure.

Two observations were made of M 42, one with the 10-ft (13 February). When the Orion Nebula and M 43 were seen on 5 October in sweep 458, Herschel noted "one of the clearest nights I have ever had". Another nebula was discovered: NGC 1999 (IV 33), located 1.2° south of M 42. The object is described as "A star with a very strong burr all around." Actually, the 9.5 mag nebula is enlightened by the 10.9 mag star V380 Ori. There is a stunning dark structure, looking like a keyhole.[588] It measures only 15" and was, of course, not perceived by Herschel. NGC 1999 was again observed in sweep 468 (1 November): "Very bright or rather a nucleus with a milky nebulosity chiefly on the preceding side, of no great extent." The remarkable nebula was sketched on 24 February 1786 (Figure 2-108).

Some very bright objects crossed the field of view in 1785. On 12 March (sweep 385), Herschel encountered Pollux (β Gem). The 1.1. mag star "passed, but its light was too bright to attempt taking its passage". On 1 September (sweep 430), Fomalhaut (α PsA) with 1.2 mag was seen "pretty accurate but the star was too bright to be very exact". Due to its brightness, the meridian passage could not be accurately measured. Even brighter was another visitor: Jupiter, passing the field on 7 November at 9:15 pm (sweep 469): "The light of Jupiter very strong. Jupiter is so bright that I cannot look at it." And three minutes later "The light of Jupiter still effects the field." Finally, Herschel saw Betelgeuse (α Ori) on 28 December (sweep 496).

The sweeps of 1785 also brought 14 new double stars. The most prominent are 39 Eri (N24) and 72 Vir (N27), discovered on 31 January (sweep 362) and 5 March (sweep 380).

Concerning the construction of large telescopes, a major step was made this year. Herschel had long thought about an instrument that was considerably larger than a 20-ft. Already in January 1781 he had planned a 30-ft telescope with a 36-inch mirror, installed on a pole mounting, similar to that for the 'small 20-ft'. Due to technical problems when making the mirror, the project was terminated.

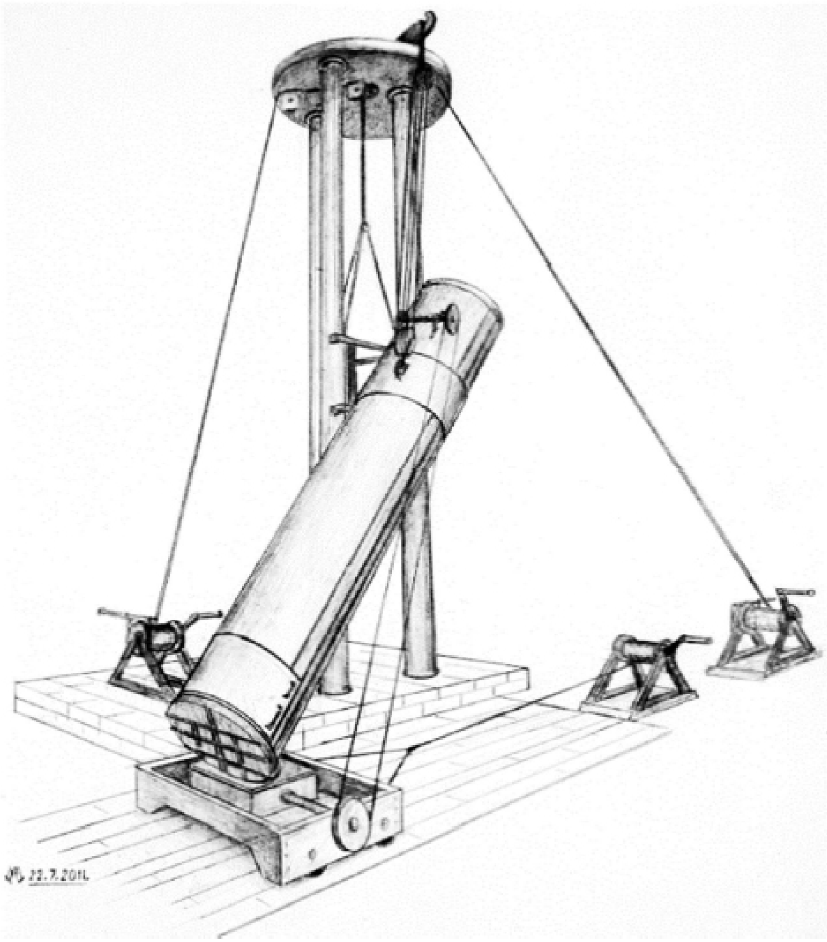


Figure 2-109: Already in January 1781, Herschel had planned to build a 30-ft reflector with 36 inches aperture. Based on his notes, Andreas Maurer has drawn the instrument in 2011.[589]

But Herschel never gave up – and thought even bigger. The main problem, of course, was the money. When discussing the issue with his friend Joseph Banks, President of the *Royal Society*, he found a solution:[590]

I thought it prudent to request the favour of the President of the R.S. to make an application to the King [George III]. His Majesty most graciously granted my petition, which was for the amount of the expense of the materials and of such work as carpenters,

bricklayers, and smiths can only do; intending not only to execute all the optical parts myself, but also to contrive, direct and complete the whole construction of a large telescope. It remained now only to fix upon the size of it, and having proposed to the King either a 30 or a 40 feet telescope, His Majesty fixed upon the largest.

Herschel was successful! In September 1785, the King made a first grant of £2000 for a 40-ft reflector with 48 inches aperture (another £2000 followed in August 1787). On 31 October, he supervised the casting of the first metal mirror in London. Fortunately, all went well in the factory.

2.3.6. Summary for 1785

Table 2-30 gives the statistical data of the sweeps made in 1785, starting with no. 351 on 6 January and ending with no. 503 on 31 December.

Category	Value	Remarks
number of nights	96	
longest continuous period (days)	6	27 January – 1 February
longest break (days)	27	10 June – 7 July (installation at Clay Hall)
number of sweeps	153	
sweeps per night (maximum)	7	10 Jan.
mean night (hours)	3.7	
longest night (hours)	12.3	28 Dec. (observing time 7.4 hours)
lowest elevation (°)	9	30 Dec.
highest elevation (°)	76	PD 53°, several sweeps
lowest PD (°)	15	
observed objects	731	
objects per night (mean)	7.5	
sweeps without objects	49	

new objects (all)	585	
uncatalogued objects	10	Table 5-5
re-observed objects	146	
most productive night	11 Apr.	80 objects
new objects: first	6 Jan.	NGC 850 (Gx Cet)
last	31 Dec.	NGC 5054 (Gx Vir)
brightest (mag)	6.5	NGC 2354 (OC CMa)
faintest (mag)	15.2	NGC 4069 (Gx Com)
smallest (")	18	NGC 3196 (Gx Leo)
multiple	30	24 pairs
Messier objects:	26	
first observation	1	
first with 20-ft	6	
new stars: double	14	
new garnet stars	3	
star gages	350	
vacant places	60	

Table 2-30: Sweep statistics for 1785.

The year started with the change from 1690 to the equinox of the date. The bar index and the 'PD clock' were installed. The first northern sweeps (above the pole) were made. The monster sweep (396) brought a record number of new objects and an inspection of the Coma Cluster. The first catalogue of non-stellar objects was closed and the second paper on the 'construction of the heavens' read to the *Royal Society*, though not published that year. There was the move to Clay Hall. George III gave an initial instalment for the 40-ft telescope and soon a first mirror was cast. Two important people were guests of the Herschels and left interesting reports. In January, Jean Hyacinthe de Magellan came to Datchet and in November John Smeaton visited Clay Hall.

2.4. Herschel's first catalogue of nebulae and star clusters

2.4.1. The arduous way to its publication

The printed version of Herschel's first catalogue had some

forerunners. These documents (lists and tables, compiled by Caroline) are essential for the construction. The *Royal Astronomical Society* has archived four items contained in a folder (here called *Item1* to *Item4*) and a manuscript (*MS2*), which is a draft of the published catalogue (*C1000*).

The folder is titled 'Several Catalogues & Indexes of Neb. & Clusters of stars used before their General catalogue was introduced'.[591] Here Caroline's unpublished 'General catalogue', compiled in October 1802 after the end of the sweep campaign, is meant.[592] The folder contains a memorandum, written by her in 1819 at Slough: "The latter [General catalogue] is not what it ought to be, and if I can find time I wish to deliver one calculated for Jan. 0, 1800. May 1st 1819. C.H." Here she announced the (unpublished) *Zone Catalogue*, compiled for John and finished in 1827.

On the front page of the archived manuscript, we read: 'Catalogue of 1000 new Nebulae in Classes'.[593] Unfortunately, this important document, sent to the *Royal Society*, is missing (here called *MS1*); it is not in their archive. But there is a copy (*MS2*), Caroline's working exemplar, showing additions and corrections; it is titled 'Catalogue of 1000 new Nebulae and Clusters of Stars'. The investigation presented below shows that there must have been a definitive manuscript (*MS3*). Herschel's 'Catalogue of One Thousand new Nebulae and of Clusters of Stars' (*C1000*) appeared 1786 in the *Philosophical Transactions*.[594] Table 2-31 lists all relevant documents.

Doc	Title	Entries	Date (sweep)	Equinox	Remarks
Item1	Catalogue of 1000 new Nebulae & Clusters of Stars	1034	28 Apr. 1785 (404)	1785	classes 1–8
Item2	Right ascension and Polar distance of Nebulae & Clusters	(38)	15 Mar. 1784 (174)	1785	fragment
Item3	Index to new Nebulas & Clusters of Stars	742	20 Dec. 1784 (349)	1690	3 tables, trial
Item4	Places of new Nebulae and Clusters of Stars	1567	3 Jun. 1786 (572)	1690/1785	'master list'
MS1	Catalogue of 1000 new Nebulae in Classes	997	20 Mar. 1786 (542)	-	not archived
MS2	Catalogue of 1000 new Nebulae and Clusters of Stars	1000	24 Oct. 1786 (622)	-	working
MS3	Catalogue of One Thousand new Nebulae and of Clusters	1000	24 Oct. 1786 (622)	-	not archived
C1000	Catalogue of One Thousand new Nebulae and of Clusters	1000	Nov./Dec. 1786	-	printed in PT

Table 2-31: Caroline's documents, leading to the first Herschel catalogue, printed in the *Philosophical Transactions* (PT).

Since no key date is specified in the documents, their chronological order and the interdependency of their data must be derived from the handwritten information – a rather difficult task. In all four

items, the objects are sorted by discovery date, but the individual 'General numbers' differ. Fortunately, the process led to a final numbering system, presented in Caroline's 'General catalogue'. In this book the designation 'GN' is used, running from 1 to 2508. For Herschel's first catalogue, the magical number is 1000. We will see that the way to reach it was anything but straight.

Item3 contains three tables, starting with Caroline's 'Index' (see Figure 2-21). Being the shortest object list among the four items, it obviously appeared first (*Item2* is only a fragment).[595] The table has four columns: object number (no heading), AR, PD, sweep number & remarks (no heading). The first entry is the Double Cluster in Perseus (NGC 869/84), observed on 2 October 1780 with the 7-ft; the last (no. 742) is the galaxy NGC 4179 in Virgo, seen on 20 December 1784 in sweep 349. The position is for 1690. The data of the first entries are rather poor. The basic information comes from Caroline's first version of the sweep records ('Original'). The final entry coincides with the equinox change from 1690 to 1785, which was applied to the reference stars only (1785 positions for objects appear much later).

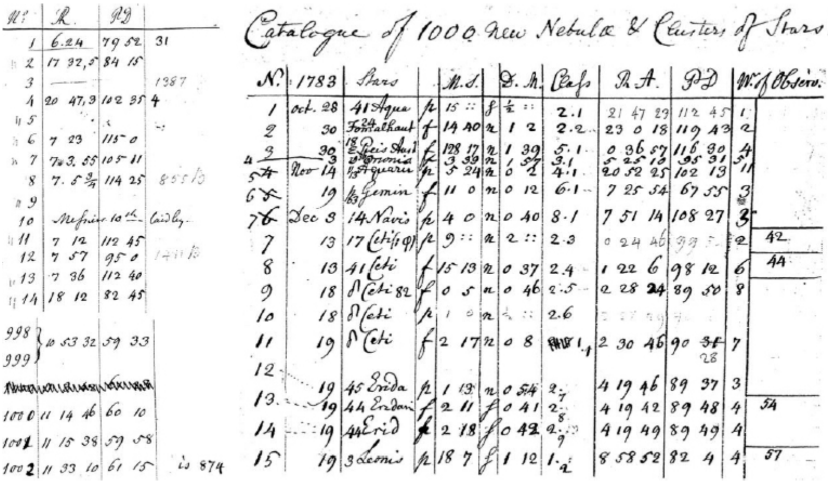
The 'Index' provides an initial overview of the observed objects, which neglects duplicate entries. The last object (no. 742) is a typical example: it is identical to no. 91.[596] Actually, some Messier objects are in the list. Considering the poor quality of the positions, it was still too difficult for Caroline to decide whether an object was new or already observed. When the data became more reliable over the time, it was easier for her to recognize identical entries. We now know that William discovered 680 objects until 20 December 1784; 158 of them were re-observed in that period.

Caroline added two tables to the 'Index'. The first shows a preliminary classification scheme, defining eight steps: 1st class to 8th class (Table 2-9). However, only 59 objects are classified, observed up to 26 December 1783. In the second table, 120 objects are ordered by AR hours (I to XXIV). Obviously, both tables were only a trial and thus not continued.

Item4 comes next, due to the fact that it contains more objects (1567) than the 'Index' of *Item3*. The new document, here called 'master list', offers four columns: No., AR, PD, sweep number and

remarks (no heading). The numbering is revised: the final entry of the 'Index' (no. 742) is now listed as no. 758, which indicates that 'objects' were actually added. There still was no thorough cleaning, i.e. identifying double entries or removing Messier objects (like M 10, M 58, M 87 or M 89). What is the 1000th entry of *Item4*? It refers to the 13.2 mag galaxy NGC 3713 in Leo, found on 11 April 1785 in the record sweep 396 (see section 2.3.3). It is GN 936 in the final numbering system (used as the fixed point here). Thus, 64 entries were eventually deleted. Only a few corrections can be traced in *Item4*: a former number '1000' is crossed out; this entry had referred to NGC 3629 (II 338), discovered in sweep 393 (6 April 1785). Moreover, 11 entries were identified, but still kept; for instance, in the remarks for no. 758 we read "is 58". Up to no. 758, all positions were taken from *Item3*. They are given for 1690 (this standard would be kept for some time).

Obviously, Herschel knew that the magical number '1000' in *Item4* was not reliable. Therefore, the list had to be expanded by further sweeps. Almost every clear night, new objects came to it. At the end of April, he was certain to have found the 1000th object – a milestone, which should be announced. The success was significant: he had exceeded *Messier Catalogue* by a factor 10. Consequently, a catalogue of 1000 objects, giving their position and type, must be published immediately. Since a classification scheme has already been created in *Item3*, an object type was available now. However, the positions caused a problem: Were the determined coordinates reliable and which equinox should be used? But prior to this, it had to be absolutely certain that the catalogue contains exactly 1000 individual objects. A thorough search for duplicate entries and hidden Messier objects was needed. The result can be seen in *Item1*, representing the first draft of the published catalogue (Figure 2-110).



N°	R	PD	
1	6.24	79 52	31
2	17 32,5	84 15	
3	——		1387
4	20 47,3	102 35	4
5			
6	7 23	115 0	
7	7h 3. 55	105 11	
8	7. 5¾	114 25	[illegible]
9			
10	Messier 10th		[illegible]
11	7 12	112 45	
12	7 57	95 0	[illegible]
13	7 36	112 40	
14	18 12	82 45	
998 999	10 53 32	59 33	
1000	11 14 46	60 10	
1001	11 15 38	59 58	
1002	11 33 10	61 15	is 874

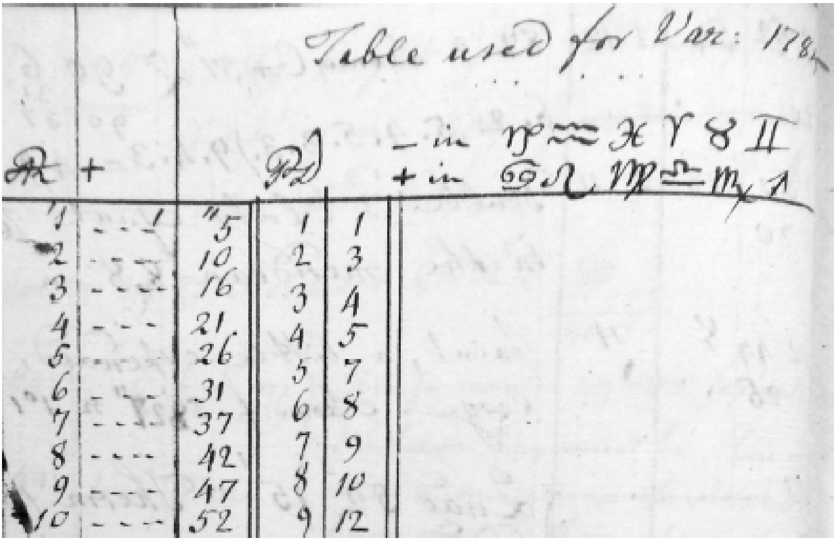
Catalogue of 1000 new Nebulæ & Clusters of Stars.

N°	1783	Stars		M.S.		D.M.	Class	RA	PD	W. of Observ.	
1	oct. 28	41 Aquar	p	15 ::	f	½ ::	2.1	21 47 29	112 45	1	
2	30	24 Fomalhaut	f	14 40	n	1 2	2.2	23 0 18	119 43	2	
3	30	18 Piscis Aust	f	128 17	n	1 39	5.1	0 36 57	116 30	4	
4	3	Orionis	f	3 39	n	1 57	3.1	5 25 10	95 31	5	
5	Nov 14	Aquarii	p	5 24	n	0 2	4.1	20 52 25	102 13	11	
6	19	63 Gemin	f	11 0	n	0 12	6.1	7 25 54	67 55	3	
7	Dec 3	14 Navis	p	4 0	n	0 40	8.1	7 51 14	108 27	3	
7	13	17 Ceti	p	9 ::	n	2 ::	2.3	0 24 46	99 [illegible]	2	42
8	13	41 Ceti	f	15 13	n	0 37	2.4	1 22 6	98 12	6	44
9	18	δ Ceti 82	f	0 5	n	0 46	2.5	2 28 24	89 50	8	
10	18	δ Ceti	p	1 0	n	[illegible]	2.6	[illegible]	[illegible]		
11	19	δ Ceti	f	2 17	n	0 8	1.1	2 30 46	90 ~~31~~ 28	7	
12	19	45 Eridani	p	1 13	n	0 54	2.7	4 19 46	89 37	3	
13	19	44 Eridani	f	2 11	f	0 41	2.8	4 19 42	89 48	4	54
14	19	44 Erid	f	2 18	f	0 42	2.9	4 19 49	89 49	4	
15	19	3 Leonis	p	18 7	f	1 12	1.2	8 58 52	82 4	4	57

Figure 2-110: Caroline's document: *Item4* (left) and *Item1*, a first draft of the final catalogue; note that the eight classes are now represented by Latin numbers (1–8).

The objects were selected from *Item4*. Caroline's work can be traced in the last column of this 'master list'. There are two numbers: one refers to the sweep, the other is a new running number (1 to 1000). Duplicate entries and Messier objects were ignored. The resulting list (*Item1*) gives positions, but they obviously differ from their source: we now see 1785 coordinates.

How were the 1690 positions precessed? The *British Catalogue* gives the 'variations' in AR/PD for 72 years for the listed stars. Caroline presents these data in her zone catalogue of Flamsteed stars (also calculating the annual precession). But this information is useless for object coordinates. Caroline had to create a table, listing the precession for fixed values of AR and PD. Indeed, there is one at the end of *Sweeps No. 3* (Figure 2-111), named 'Table used for Var[iations]: 1785.' Now, by interpolation, the precession for each object could be calculated.



AR	+		PD	
1	- - - 1	"5	1	1
2	- - -	10	2	3
3	- - -	16	3	4
4	- - -	21	4	5
5	- - -	26	5	7
6	- - -	31	6	8
7	- - -	37	7	9
8	- - -	42	8	10
9	- - -	47	8	10
10	- - -	52	9	12

Figure 2-111: Caroline’s table for the 1785 precession of objects in *Sweeps No. 3*.

Of course, for 1000 objects this task took some time. We shortly will reveal the finishing date of *Item1*. The first column (‘N.’) gives the revised object number. The list is sorted by discovery date (second column). The first entry is the galaxy NGC 7184 in Aquarius, discovered on 28 August 1783; the 1000th is NGC 5937, a galaxy in Serpens, discovered on 14 April 1785 in sweep 400. It corresponds to no. 1061 of *Item4*. Thus, Caroline rejected 61 entries from the ‘master list’.

The second column (‘Stars’) gives the reference star. We will show, that it corresponds with the column ‘Nr. of Observ.’, telling us how often an object was observed. Any value greater than 1 implies that observations were identified, i.e. entries in the ‘master list’ (*Item4*) refer to the same object. However, the bare number does not show which observations (sweeps) are meant. This important information results from a careful analysis of the sweep data, yielding the chronology for each object (56% of the first 1000 objects were seen only once).

Of course, all discoveries were made until 14 April 1785 (number 1000). But what about further observations of an object? Obviously,

the very last of these gives us the closing date of the list. An examination of *Item1* yields 24 February 1786, which is almost a year later than the discovery date of the 1000th object! The crucial object is NGC 5147, a 11.8 mag galaxy in Virgo, found on 24 January 1784 (sweep 124). The reference star was 75 Leo, nearly at the same PD, but preceding the nebula by more than 2^{h}. Thus, the 1690 position, given in *Item4* (no. 94), is pretty poor (about 16' west). In *Item1* the object is listed as no. 64, the number of observations is 2. The second was on 24 February 1786 (sweep 532). Now the reference star was 92 Vir, located only 30^{m} east, giving a better position. *Item1* mentions the new star, the corresponding differences in AR and PD and the resulting coordinates for 1785. The case shows that Caroline has worked on the 'Catalogue of 1000 new Nebulae & Clusters of Stars' until the end of February 1786! Thus, she had enough time to calculate the 1785 coordinates for all objects. The last column (no heading) gives the sweep number relating to the discovery date.

But *Item1* has actually more to offer: a new classification scheme. It differs from the trial in *Item3* (see Table 2-9). Though there are still eight classes, their meaning has changed (Table 2-32). The information comes from William's descriptions in the sweep records. The objects in each class are numbered, corresponding to the chronological order of the list. The result is presented in the column 'Class'. For the sake of simplicity, Arabic numbers are now used, replacing 1st Class, 2nd Class etc. of *Item 3*. The first object in *Item1* (NGC 7184) is designated as 2.1, the 1000th (NGC 5937) as 2.401.

Class (*Item 1*)	Class (*C1000*)	Description (type)	Entries	First object
1	I	bright nebulae	93	NGC 1055
2	II	faint nebulae	401	NGC 7184
3	III	very faint nebulae	374	part of M 42
4	IV	planetary nebulae	29	NGC 7009
5	V	very large nebulae	25	NGC 253
6	VI	very compressed and rich clusters of stars	19	NGC 2420
7	VII	pretty much compressed clusters of large or small stars	18	NGC 1662
8	VIII	coarsely scattered clusters of stars	41	NGC 2509

Table 2-32: Caroline's classification scheme of *Item1*, using Arabic numbers; the published catalogue (*C1000*) shows Latin numbers. The number of entries in each class is based on the first 1000 objects in her table.

Compared to the trial scheme of *Item3*, the focus turned from size to brightness in the first three classes. Class 1 objects are described in the sweep records as ‘very bright’, ‘bright’ or ‘considerably bright’. For class 2 we have the categories ‘pretty bright’, ‘faint’ or ‘pretty faint’. Class 3 objects are ‘very faint’ or ‘extremely faint’. Class 4 is new and concerns nebulae appearing ‘planetary’ but also cases, not fitting in any other class. Class 5 represents extended nebulosities (often larger than the field of view). Classes 6 to 8 are star clusters of different size, number of stars and concentration. Resolved globular clusters are in class 6, open clusters mainly in 7 or 8.

When *Item1* was compiled, Caroline realized that one object was forgotten: the “small distinct nebula of an extended shape”, found in M 42 on 3 November 1783 (sweep 15).[597] Caroline inserted it as ‘3.1’ between no. 3 and 4. Fortunately, the correction was made, when writing the first page. So only two other class 3 objects were concerned, getting new numbers. When entering no. 173, she became aware that the object is M 60 in Virgo. It was deleted – and the total object number remained constant!

Of course, while making the catalogue, many more objects were found and Caroline continued her ‘master list’ (*Item4*), calculating 1690-positions for the new objects from the sweep data. This influenced *Item1*. At first it ended with no. 1000, marked by a closing line (Figure 2-112). The final object was found in sweep 400 (14 April 1785). However, this sweep has brought one more object, the galaxy NGC 6118 in Serpens. Of course, this is no. 1001 – and we actually find this number in the last column of *Item4*. Before Caroline added it to *Item1*, she wrote a new heading: ‘Catalogue of a second thousand nebulae’. The collection of new objects was continued until sweep 404. The last entry is no. 1034, the galaxy NGC 4214 in Canes Venatici, found on 28 April 1785 (it corresponds to no. 1095 of *Item4*).

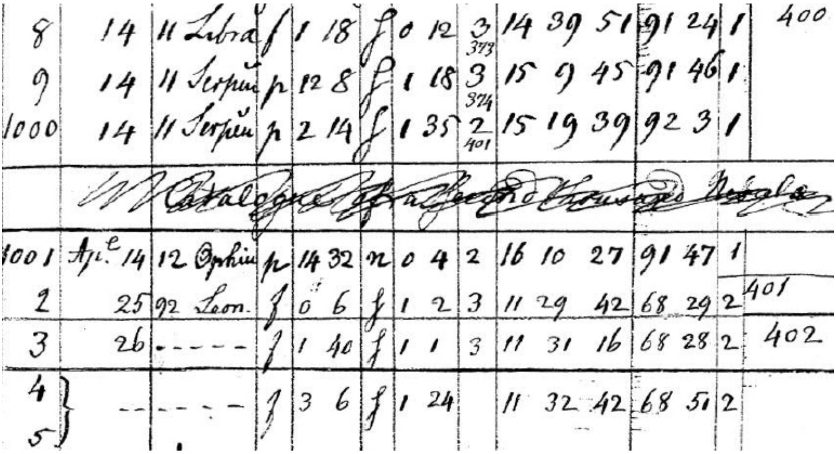


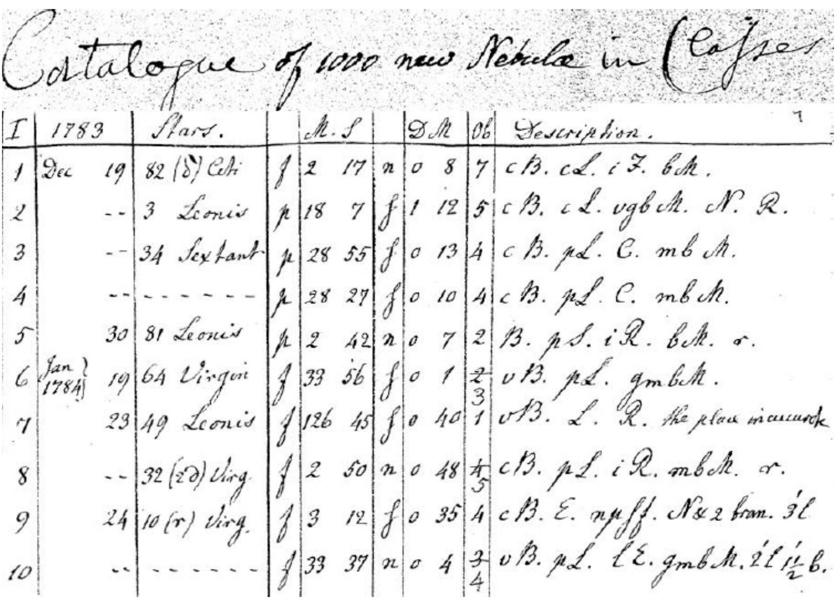
Figure 2-112: The 1000th entry in Caroline's *Item1* (see text).

Item1 is obviously not the version published in the *Philosophical Transactions*. The form deviates significantly from it: the printed catalogue (*C1000*) is sorted by class and gives no coordinates! What has happened?

The critical point were the coordinates. Did Herschel omit them because he questioned their reliability? If so, why there are relative positions, from which the coordinates are mere derivations? There must be another reason. Probably he was in doubt if the 'equinox of the date' (1785) was not a good choice.[598] Because many discoveries were expected in the upcoming sweeps, Herschel was sure that additional catalogues would follow. Thus, the equinox would more or less depend on the publication year (the following catalogues appeared 1789 and 1802). Any inconsistent treatment should be avoided. Of course, a future 'General catalogue' should have a standard equinox – and 1800 would be the natural choice. He may have thought about calculating such standard positions for his first catalogue, but this would be a time-consuming task (for Caroline). William was not willing to wait any longer and, consequently, completely omitted coordinates. This fact was criticized by later astronomers and led to a certain disregard for Herschel's catalogues, which appeared unwieldy. As mentioned above, Caroline later calculated 1800 positions and actually compiled a 'General catalogue', though not for the public.

Since a main feature of a catalogue of non-stellar objects – coordinates for a standard equinox – was now missing, the focus was on morphology, i.e. object type and visual appearance. This consideration led to a new format: sorting the objects by class and adding a standardized description. Caroline implemented this idea, picking out the objects of each class from *Item1*. Since they were already sorted by discovery date, making a new list was not a difficult task. She was experienced in data processing – and worked fast. The result is the 'Catalogue of 1000 new Nebulae in Classes'. We do not have this document (*MS1*), sent to the *Royal Society*. Fortunately, a copy is archived (*MS2*) at the *Royal Astronomical Society*; it was Caroline's working exemplar (Figure 2-113). The columns for the discovery date, number of observations, reference star and relative position were kept. But there are essential differences:

- objects sorted by classes I–VIII (Table 2-32) and discovery date (running number),
- added standardized description
- no 'General number' (obviously, Herschel feared later changes – he was right),
- no coordinates,
- no sweep number.


Catalogue of 1000 new Nebulae in Classes

1

I	1783		Stars.		M. S		D M	Ob	Description.
1	Dec	19	82 (δ) Ceti	f	2 17	n	0 8	7	cB. cL. iF. bM.
2		--	3 Leonis	p	18 7	f	1 12	5	cB. cL. vgbM. N. R.
3		--	34 Sextant	p	28 55	f	0 13	4	cB. pL. E. mbM.
4		--	-------	p	28 27	f	0 10	4	cB. pL. E. mbM.
5		30	81 Leonis	p	2 42	n	0 7	2	B. pS. iR. bM. r.
6	Jan 1784	19	64 Virginis	f	33 56	f	0 1	2 3	vB. pL. gmbM.
7		23	49 Leonis	f	126 45	f	0 40	1	vB. L. R. the place inaccurate
8		--	32 (2d) Virg.	f	2 50	n	0 48	4 5	cB. pL. iR. mbM. r.
9		24	10 (r) Virg.	f	3 12	f	0 35	4	cB. E. npff. Ns 2 bran. 3'l
10		--	-------	f	33 37	n	0 4	3 4	vB. pL. lE. gmbM. 2'l 1½ b.

Figure 2-113: Caroline's copy of the published manuscript.

Moreover, based on the number of observations there is a different closing date. That of *Item1* is 24 February 1786 (sweep 532), but now we get 20 March 1786 (sweep 542). The final addition concerns an 11.8 mag galaxy in Hydra: III 289 (NGC 2389), discovered on 10 March 1785 in sweep 382. In *Item1* (no. 798) we have only one observation (reference star 6 Crt), while in the manuscript the number is 2. Although the second observation (made in sweep 542) used the same reference star, the relative position is slightly different.[599]

According to the actual closing date, the manuscript (*MS1*) was sent to the *Royal Society* at the end of March 1786. This fits well to the reading date: 27 April 1786. Although William's 16-sided introduction is not dated, there is a hint: "I began at last intirely to new model the machinery of the polar distance piece [PD clock]; and on Sept. the 24, 1785, completed one". Caroline wrote about this issue in her diary:[600] "An account of the discoveries made with the 20 feet and the improvements of the mechanical parts of the instrument during the winter of 1785 is given in the Cat. of the 1st 1000 New Nebula." Moreover, the introduction explains the abbreviations used in the descriptions. They can already be seen on the first page of Caroline's *Sweeps No. 5*, beginning on 4 October 1785. Thus, it is likely that both *Item1* and the manuscript were compiled in parallel. The object table is followed by notes.

The ongoing stress, due to the nightly observations, exhausted the siblings. Over the day, Caroline reduced the observations, which continued in 1786 with the same intensity. Indeed, it is a miracle how they manged their immense daily stint. Additional work came from activities, not directly related to observing. There was the move from Datchet to Clay Hall in June 1785. In October, William casted a mirror for the 40-ft.

When was the catalogue published in the *Philosophical Transactions*? The eminent scientific journal was published twice a year. Although the issues are dated '1st January' and '1st June', they never appeared on these dates. After reading a paper to the *Royal Society*, editing and printing normally took several months. In total, the two issues of volume 76 contain 28 papers of rather different lengths.

Those read to the end of April (like Herschel's) found their way in the January issue (17 in this case), which might be on the market no earlier than June. Surprisingly, the first issue of 1786 does not contain Herschel's catalogue! We find it in the second as the 27th paper (of 28).601 The July issue appeared not until the end of the year. What caused the delay?

It is normal that the editor stays in contact with the author. Pending remarks or changes requested by the *Royal Society*, Caroline used the time to add new data to her working copy (*MS2*). We can see it by a remark at the end of *Item1*, which was still the reference document: "Number of observations changed after 27 March 1786. CH to be added in the proper places." Indeed, there are corrections in the number of observations after the closing date (20 March). We also find them in the descriptions. It is astonishing that they end with that for III 201. There are no descriptions for objects of classes IV to VIII (even the class title is missing). Since we do not have *MS1*, there are two possibilities: either the manuscript (*MS1*), sent to the *Royal Society*, had no column 'Description' or the text was only partly copied to *MS2*. The former is unlikely, because the abbreviations used in the standardized description, are explained in the introduction, which certainly appeared in *MS1*. Obviously, Caroline refrained from copying the amount of text, adding only selected remarks like the following: for three objects, discovered by her, 'CH' is added in the descriptions. This concerns V 1, V 19 and VII 13 (see below).

Another point is crucial. Caroline found time to check the *Item1* entries once more – and discovered three problematic cases that she had previously overlooked: no. 429 = no. 435 (globular cluster NGC 6553 in Sagittarius), no. 442 is the open cluster M 25 in Sagittarius and no. 480 = no. 461 (open cluster NGC 6940 in Vulpecula). After deleting the three entries, Caroline now faced 997 objects. Therefore, three new ones were needed to restore the magical number 1000! Fortunately, *Item1* had 1034 entries, so the objects with numbers 1000–1003 were taken as a substitute (Table 2-33).

No.	Action	H	Object	Remarks
429	delete	5.10	NGC 6553	identical to no. 435 (4.12)
442	delete	8.14	M 25	
480	delete	7.10	NGC 6940	identical to no. 461 (7.8)
1001	add	2.402	NGC 6118	sweep 400
1002	add	3.375	NGC 3804	sweep 401
1003	add	3.376	NGC 3821	sweep 402

Table 2-33: Caroline's actions in *Item1* to get the exact number of 1000 objects for the published catalogue.

Although all objects (except the first three) needed new numbers, this change in column 'N' was not made. But Caroline crossed out the heading 'Catalogue of a second thousand new nebulas' after no. 1000 and entered a new line after no. 1003 (Figure 2-112). Finally, we have a new 1000th object: NGC 3821 (III 376), a 12.9 mag galaxy in Leo, found on 26 April 1785 in sweep 402. Nevertheless, the changes led to the final numbering system, the 'General number' (GN). Thus, we have III 376 = GN 1000, replacing II 401 (NGC 5937), which is now GN 997.

More important was the revision of the numbers in column 'Class' of *Item1*, because it essentially influenced *MS2* (the change of the object numbers was irrelevant, since they were omitted here). Class II has one object more (402) and class III two (375 and 376). As they were added at the end, nothing changed in the tables. This is different in classes V, VII and VIII, getting one additional entry. Since V 10, VII 10 and VIII 14 are involved, we get the following changes: V 11–25 to V 10–24, VII 11–18 to VII 10–17, VIII 15–41 to VIII 14–40. The 'CH' objects are V 1 (unchanged), V 18 and VII 12. Alas, the catalogue notes were not corrected! For V 1 we read: "I have marked it with the initial letters CH of her name; see also V 19, discovered Aug. 27, 1783, and VII 13, discovered Feb. 26, 1783." This text was taken over to the published catalogue, later causing some trouble.

Of course, Joseph Banks, responsible for of the *Philosophical Transactions*, halted the production of Herschel's paper. An appearance in the January issue was out of reach and it was shifted to June, offering sufficient time for Caroline to make updates. The

delay was most welcome as some events were imminent, like the move from Clay Hall to Slough. Moreover, William planned a journey to Hanover in the summer. And, of course, sweeping had to be continued.

In the summer, especially in the time William was away from home, Caroline found time for some important tasks.[602] This concerns the catalogue, but also the object positions in the sweep records. There is a ‘memorandum’ in her first autobiography: “All the Neb[ulae] are registered in Fl[amsteed’s] time and PD as far as the single nebula in 572 Sweep. The number of the Neb is 1567.”[603] This is the final object number (and sweep) of *Item4*. The corresponding date is 3 June 1786 (which also might be that of the memorandum).

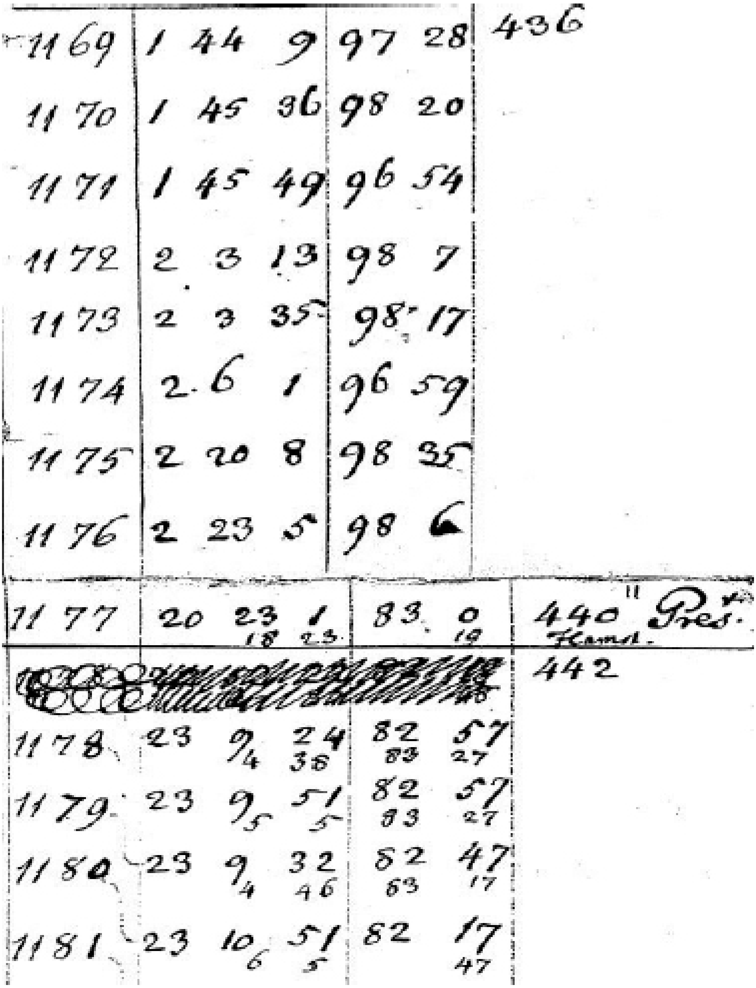
This was a signal to change the equinox for the newly discovered objects. For this issue, another date is important: 24 September 1785. In that night (sweep 440) the ‘PD clock’ was put into use. Caroline noted about the positions (*Sweeps No. 4*): “By the present time & PD.” The new device allowed the direct reading of the PD at her desk (via the ‘PD string’). It replaced a tedious task: measuring the ‘zero’ (vertical starting point) and breadth of the sweep from two stars (observed in the finder), reading off the index number of an object and calculating the corresponding PD difference from the ‘zero’. However, in the sweep records (‘Original’) only the star positions were calculated for the ‘equinox of date’ (1785). This does not concern the objects: the records give no positions!

Things changed in June 1786. Caroline’s diary entry for the 29th reads: “I began some time ago with the last sweep which is booked in the old register (Fl. Time and PD) viz. 571 and at different times I booked 570, 569, 568, 567, 566, 565. To day I booked 564, 563 is marked not to be registered 560 & 561 I was obliged to pass over on account of some difficulty.” Obviously, she calculated new positions, starting with sweep 572 and working backwards to 440. The new data were added in the records, which can be seen by a different writing. On the 31st she noted: “I booked 558, 557 & 554 (556, 555 I was obliged to leave out on account of some difficulty). Mem. I find I cannot go on fast enough with the registering of sweeps to be revisable to the Cat. of Nebulae. Therefore, I will

begin immediately to recalculate them, and hope to finish them before you [William] return. I think the consequences will be bad of registering the sweeps backwards."

The time-consuming task of adding 1785-positions for recorded objects rivalled with the final work on the first Herschel catalogue. In July, Caroline shifted the priority to the latter:[604] "I attempted to register all discovered Nebulae; after my brother had left me; which was wanted for revising the M.S. of the Cat. of the 1st 1000 Nebulae, expected at his return for correction from the printer." For 1 August we read: "I have calculated 100 nebulae today." And further: "To day I calculated 150 nebulae" (2 August), "I calculated 100 nebulae" (9 August), "Calculated 100 nebulae" (10 August). Finally, on 11 August:[605] "I completed to day the Cat. of the 1st 1000."

It is not known when Caroline finished her work on the sweep records, perhaps at the end of 1786. On the last page of *Sweeps No. 4*, we only read: "Sweep 440. September 24, 1785. The Nebulae are calculated to the present time and polar distance." Of course, the change of equinox for the object positions influenced the 'master list' *Item4* (Figure 2-114). This is indicated by the object, found on the crucial date 24 September 1785 (sweep 440). It is no. 1177, the open cluster NGC 6934 in Delphinus. As usual, the last column gives the sweep, but two words are added: "Pres." and (in a new row below) "Flamst." The first indicates that the position is now given for the 'present equinox' (1785). The second row gives the position for 1690, which is now inserted (in smaller numbers). Starting with no. 1386 (sweep 512, 27 January 1786), *Item4* gives the position for 1785 alone, i.e. there is no second row.[606] Probably, the work on the 'master list' and the sweep records ran in parallel.

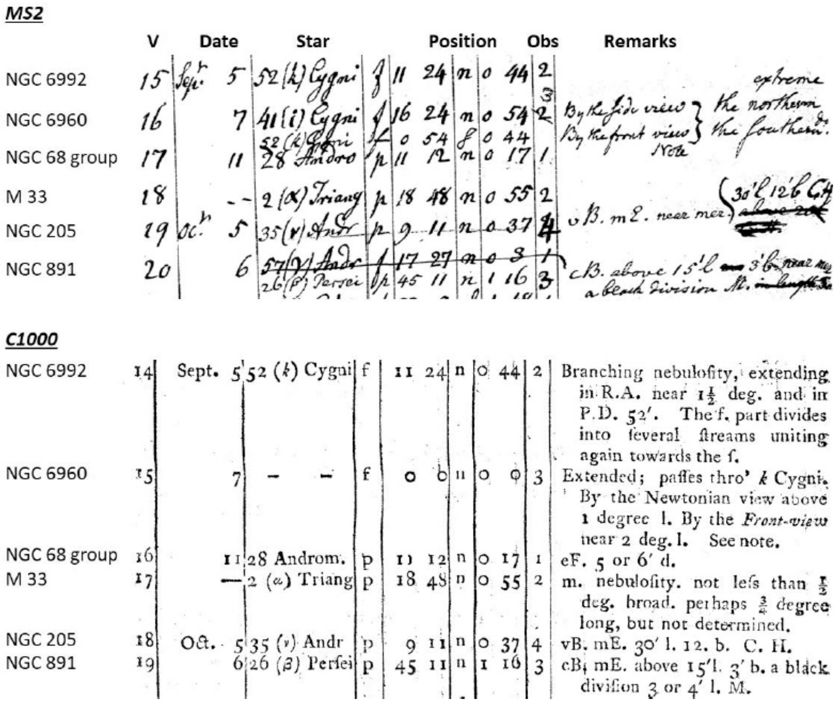


1169	1 44 9	97 28	436
1170	1 45 36	98 20	
1171	1 45 49	96 54	
1172	2 3 13	98 7	
1173	2 3 35	98 17	
1174	2 6 1	96 59	
1175	2 20 8	98 35	
1176	2 23 5	98 6	
1177	20 23 1 / 18 23	83 0 / 19	440" Pres. Hand.
[illegible]	[illegible]	[illegible]	442
1178	23 9 / 4 24 / 38	82 57 / 83 27	
1179	23 9 / 5 51 / 5	82 57 / 83 27	
1180	23 9 / 4 32 / 46	82 47 / 63 17	
1181	23 10 / 6 51 / 5	82 17 / 47	

Figure 2-114: Caroline's change of object positions to the 'equinox of the date' (1785) in *Item4*, her 'master list' (see text).

Back to the revision of the *C1000* manuscript. Although it was called 'completed' on 11 August, the work did not end. Again, this can be traced by column 'Nr. of Observ.' in *MS2*: obviously, many numbers are corrected. Especially interesting are cases, where observations made after spring 1786, were accounted. The crucial object is V 19 in *MS2* (the galaxy NGC 205 near M 31, listed as V 18 in *C1000*); here the number is changed from 3 to 4 (Figure 2-115). The fourth observation was made in sweep 621 on 24

October 1786! The same date appears for V 19 in *C1000*, the edge-on galaxy NGC 891 in Andromeda. This date also resolves a mystery in the published catalogue, concerning V 15 (NGC 6960), the western part of the Veil Nebula in Cygnus. In the table for the 'Fifth Class' we read about its size: "By the *Front-view* near 2 deg. long." A similar remark is added in *MS2*. The front-view observation was made on 18 October 1786 (sweep 615). Without knowing the actual story, one would ask: How is this possible when Herschel's paper was read 18 months earlier?



NGC 6992	14	Sept. 5	52 (k) Cygni	f	11 24	n	0 44	2	Branching nebuloſity, extending in R.A. near 1½ deg. and in P.D. 52′. The f. part divides into ſeveral ſtreams uniting again towards the f.
NGC 6960	15	7	– –	f	0 6	n	0 9	3	Extended; paſſes thro' k Cygni. By the Newtonian view above 1 degree l. By the *Front-view* near 2 deg. l. See note.
NGC 68 group	16	11	28 Androm.	p	11 12	n	0 17	1	eF. 5 or 6′ d.
M 33	17	—	2 (α) Triang	p	18 48	n	0 55	2	m. nebuloſity. not leſs than ½ deg. broad. perhaps ¾ degree long, but not determined.
NGC 205	18	Oct. 5	35 (ν) Andr	p	9 11	n	0 37	4	vB. mE. 30′ l. 12. b. C. H.
NGC 891	19	6	26 (β) Perſei	p	45 11	n	1 16	3	cB. mE. above 15′l. 3′ b. a black diviſion 3 or 4′ l. M.

Figure 2-115: Class V objects in Caroline's manuscript (*MS2*) and the published catalogue (*C1000*). Note the different V numbers, the corrected observation (Obs) and the new descriptions. The date for NGC 6992 is wrong; it is 'Sept. 6'.

Although the corrections concerning the number of observations and the descriptions are all visible in *C1000*, the reference stars and the relative positions were not updated after April 1786. Even a correction, given at the end of *MS2* ('Errata & Emendata'), was not considered. It concerns a second observation of II 1 (NGC 7184),

made in sweep 609 (13 October 1786), giving a better relative position.

The final, not archived manuscript (*MS3*) must contain all descriptions and notes (missing in *MS2*). It probably was sent to the *Royal Society* at the end of October 1786. The paper still found its way into the June issue, published at the end of the year. It was a long journey from the discovery of the 1000th object in April 1785 to the printed catalogue, appearing in late 1786. In a letter to Jean Dominique Cassini at Paris, dated 18 December 1786, Herschel announces the mailing of his catalogue. Similar advertisements were sent on 16 February 1787 to Schroeter (Lilienthal) and Bode (Berlin).[607] The latter first mentions Herschel's catalogue in April 1787.[608]

2.4.2. Structure, content and data quality

The publication has four parts: introduction, catalogue, notes, errata. We read: "The following Catalogue, which contains one thousand new Nebulae and Clusters of stars, is extracted from a series of observations (or Sweeps of the heavens), which was begun in 1783, and which I am still continuing till the while be completed." Obviously, it was planned to sweep the entire sky, visible from the Windsor area. Although the campaign that ended in September 1802 was a monumental task, the sky was not completely covered (see section 5.1.2).

The introduction describes the sweep method and their results, the arrangement of the columns (Table 2-34) and the abbreviations used for the standardized description. For the latter, some typical examples are given. 59 double and nine triple systems, seen in a single field, are assigned by a common brace; usually only one position is given.[609] Herschel's object notation was, for instance, III. 107 (here III 107 is used; compare Table 6-13).

Column	Meaning	Remarks
I. – VIII.	class number	within the classes I to VIII; } = double/ triple object
1782–1785	discovery date	month, day

Stars.	reference star	Flamsteed number (Bayer letter) and constellation
	AR sequence	f/p = object follows/ precedes the star
M. S.	AR distance	minutes, seconds (:: = uncertain value)
	PD sequence	n/s = object north/ south of the star
D.M.	PD distance	degree, arcminute (:: = uncertain value)
Ob.	observations	number of observations (until 24 October 1786)
Description.	description	standardized elements (Table 2-36)

Table 2-34: Columns in the first catalogue; horizontal strokes in columns 2 and 3 denote repetitions.

The given reference star is that used in the latest observation (until 24 October 1786), assuming that it is the most reliable. The discovery date (second column) differs in most cases from date of the reference star observation. The given relative position in the following columns was derived from this sweep.

The catalogue consists of eight tables: classes I–VIIII, sorted by discovery date (Table 2-35). The earliest date is 7 September 1782, referring to the planetary nebula IV 1 = NGC 7009 in Aquarius (found with the 6.2-inch in the third review). The final date is 26 April 1785, referring to the galaxy III 376 = NGC 3821 in Leo (the 1000th object).

The standardized description uses abbreviations, which are explained in Table 2-36. It mainly is a compact version of the text, written down by Caroline in the sweep records. It ranges from a simple ‘F’ to a long text, especially for objects of class IV or V. Often combinations are applied, like ‘vgbM’ (very gradually brighter in the middle). For four objects a reference to a drawing is given, published in Herschel’s first paper on the ‘construction of the heavens’ (1784); see Figure 2-45. The objects are: I 13 = NGC 3521

(Fig. 11), I 17/18 = NGC 3379/84 (Fig. 4), II 28/29 = NGC 3326/27 (Fig. 3), III 15/16 = NGC 3646/49 (Fig. 5), IV 2 = NGC 2261 (Fig. 7), IV 3 = NGC 2245 (Fig. 8) and IV 5 = NGC 4517 (Fig. 6). Three objects are credited to Caroline, marked by 'C.H.': V 1 = NGC 253, V 18 = NGC 205, VII 12 = NGC 2360. Unfortunately, her other discoveries were ignored (see Table 1-21). Was this William's fault?

Class	Object type	Entries	Discovery dates
I	bright nebulae	93	19 Dec. 1783 – 11 Apr. 1785
II	faint nebulae	402	28 Oct. 1783 – 14 Apr. 1785
III	very faint nebulae	376	3 Nov. 1783 – 26 Apr. 1785
IV	planetary nebulae. Stars with burs, with milky chevelure,	29	7 Sep. 1782 – 8 Feb. 1785
V	very large nebulae	24	30 Oct. 1783 – 24 Apr. 1785
VI	very compressed and rich clusters of stars	19	19 Nov. 1783 – 10 Mar. 1785
VII	pretty much compressed clusters of large or small stars	17	18 Jan. 1784 – 6 Mar. 1785
VIII	coarsely scattered clusters of stars	40	3 Dec. 1783 – 11 Mar. 1785

Table 2-35: The final classification: content of the eight class tables in the first catalogue (compare Table 2-9).

Abbr.	Meaning
B	bright
L	large
v	very
p	pretty
R	round
M	in the middle
m	much
i	irregularly
s	suddenly
r	resolvable
p, f	preceding (west), following (east)
m	milky
bran	branch
mer	meridian (in NS direction)
st	star
Cl	cluster*
sc	scattered*
F	faint
S	small
c	considerably
e	extremely

E	extended
b	brighter
l	a little
g	gradually
betw	between
er	easily resolvable
n, s	north, south
C	cometic
chev	chevelure
par	parallel (in EW direction)
ver	verified
com	compressed*
co	coarsely*

Table 2-36: Abbreviations used in Herschel's standardized description (* = used for class VI objects only).

Class	I	II	III	IV	V	VI	VII	VIII	*Sum*
Entries	**93**	**402**	**376**	**29**	**24**	**19**	**17**	**40**	**1000**
Observations									
1	**52**	**290**	**317**	**13**	**14**	**15**	**9**	**28**	**738**
2	23	75	52	11	4	1	4	8	356
3	7	25	6	1	3	2	2	4	150
4	6	10	1	3	2	1	1		96
5	4						1		25
6		1			1				12
7	1								7
8		1							8
11				1					11
Sum	170	569	443	61	45	27	32	56	**1403**
Multiple obs.	**41**	**112**	**59**	**16**	**10**	**4**	**8**	**12**	**262**

Table 2-37: Number of entries and observations for each class in the first catalogue (see text).

The number of observations ranges from 1 to 11 (Table 2-37). Altogether 1403 observations were made until 24 October 1786 (see preceding section about this date). 738 objects were seen only once (74%), 262 more than once. The largest rate of multiple observations shows class IV, 'planetary nebulae' (55%). Obviously, these were the most interesting cases. The front-runners are: IV 1 =

NGC 7009, the planetary nebula in Aquarius (11), and II 5 = NGC 1032, the galaxy in Cetus (8). The least number of observations show class III objects (16%); of course, ‘very faint nebulae’ were no targets for a further study.

Table 2-38 shows the principal content of the catalogue. 966 of the 1000 entries refer to true non-stellar objects: galaxies, galactic/ planetary nebulae, open/globular clusters. The rest are: part of objects, single/multiple stars, missing cases (’not found’); compare Table 5-7. Of the 1000 objects, we count 970 independent ones. 26 have two entries; two are listed actually three times. Thus, in total, 30 entries are obsolete. Although Caroline did her best to eliminate such cases, seven remained. They were overlooked by the Herschels, often due to incorrect positions given by Messier. Taking the 970 independent objects, 14 were discovered earlier by other observers (including Messier). Thus, there are 956 discoveries. Finally, subtracting all ‘wrong’ cases, there are 923 true non-stellar objects.[610]

Category	Number	Remarks
all objects	1000	better: ‘entries’
true non-stellar objects	966	
independent objects	970	26 double + 2 triple identities
Messier objects	7	M 8, M 20, M 33, M 47, M 49, M 91, M 95
Herschel discoveries	956	all independent objects
Herschel non-stellar discoveries	**923**	all independent non-stellar objects

Table 2-38: Object qualification.

Table 2-39 gives the object numbers relating to modern types. They do fairly match to Herschel’s eight classes. Galactic nebulae are emission or reflection nebulae (including supernova remnants).[611] The type ‘Part of galaxy’ usually refers to bright HII-regions; ‘Star’ includes all single stars, pairs, multiple stars, small groups or asterisms (star patterns). Finally, ‘Not found’ is assigned for all cases were Herschel’s place offers only a blank field. A reasonable object

is not available, which may be due to a position error or a deception. In the latter case 'non-existent' would be a better term.

Modern Type	I	II	III	IV	V	VI	VII	VIII	*Sum*
galaxy (Gx)	79	383	359	13	15	1			**850**
galactic nebula (EN, RN)		2	2	7	8				**19**
planetary nebula (PN)	1	4		8					**13**
open cluster (OC)						9	15	32	**56**
globular cluster (GC)	12	8	1	1		7			**29**
part of galaxy (GxP)	1		1						**2**
star (single, pair, group)		4	9			2	2	8	**25**
not found (NF)		1	4		1				**6**
Sum	**93**	**402**	**376**	**29**	**24**	**19**	**17**	**40**	**1024**

Table 2-39: Modern object types vs. Herschel classes.

Class I contains mainly galaxies and some unresolvable globular clusters. The exceptions: the planetary nebula I 65 = NGC 4361 (Corvus) and the galaxy part I 57 = NGC 2905, a HII-region in NGC 2903 (Leo). It is not surprising that among the faint, small objects (II, III) are 13 stars. The five missing objects are probably deceptions. Astonishingly, true (physical) planetary nebulae do not dominate class IV. One should remember that Herschel filled it with objects, not fitting in any other class; among them are galaxies (some looking cometary, Table 2-26) and galactic nebulae. The single globular cluster is IV 12 = NGC 6553 in Sagittarius, seen as an unnormal case. Most class V objects are large galaxies, but some are extended galactic nebulae. The 'not found' case is V 3 = NGC 4910 in Virgo (see Figure 2-35). Of course, most objects in class VI to VIII are open clusters; 10 are star groups. One class VI object is a galaxy: VI 4 = NGC 3055 in Sextans ("nebula or cluster of very close and faint stars").

Comparing the coordinates, given by Caroline in *Item1* (for 1785), with modern ones (for 2000), the position quality of the first catalogue can be determined. The mean errors are 16.7^s in AR and 2.6' in PD (compare Table 6-11). With respect to the mounting of the telescope and the method of getting positions, the errors are pretty small. Together with the description, the achieved precision allows a clear identification of an object in most cases.

Finally, Table 2-40 shows all objects which should bear two or more

NGC-numbers (not applied by Dreyer) or no NGC-number at all. The first case is among the 26 double entries (Table 2-17). II 6 is incorrectly identified by Dreyer as I 1.

H	NGC	GN	Sw	Date	Con	Remarks
II 48 = II 80	2672 + 2673	122 = 203	169	14 Mar. 1784	Cet	double galaxy; Figure 2-47
III 67	3473 + 3474	214	181	21 Mar. 1784	Leo	double galaxy; Figure 2-51
V 16	68 group	487	266	11 Nov. 1784	And	galaxy group; Figure 2-73
II 6	-	11	47	18 Dec. 1783	Cet	star; Dreyer: I 1
II 18	-	44	105	23 Jan. 1784	Vir	'not found'; Dreyer: II 498
II 118	-	265	187	8 Apr. 1784	Com	star pair
III 1	-	4	15	3 Nov. 1783	Ori	part of M 42; Dreyer: M 43
III 61	-	205	181	21 Mar. 1784	Cnc	star group; Dreyer: NGC 2774

Table 2-40: Herschel objects not (or incorrectly) catalogued by Dreyer or wanting two or more entries in the NGC.

2.5. Observations in 1786 – the move to Slough and Caroline's first Comet

2.5.1. The first quarter of 1786: uncatalogued objects and stars

The observing year 1786 began punctually on 1 January. The first object, the 11.6 mag galaxy NGC 1032 (II 5) in Cetus, was seen for the sixth and last time. 31 objects were observed in the three sweeps (505–507), 15 were new. NGC 1620 (II 514), an elongated 12.3 mag galaxy in Eridanus, was sketched.612 The most spectacular object is the Flame Nebula, NGC 2024 (V 28), 15' northeast of Alnitak (ζ Ori): "A wonderful milky nebulosity, divided in three or 4 large patches including a dark space, the whole cannot take up less than half a degree; but I suppose it to be much more extensive." A year earlier, when discovering NGC 2023, he missed the large nebula by 25'. It was seen again in sweep 518 (1 February). In sweep 506, Herschel discovered "A star surrounded with milky chevelure; the star is not central." This is NGC 2071 (IV 36) in Orion, a reflection nebula 14' north of M 78. The Messier object appeared shortly before and for the first time in the 18.7-inch reflector: "Very large milky nebulosity terminating suddenly on the north side; contains 2 pretty large stars; they are on the north side."

However, the very first find of the year (in sweep 505) remained uncatalogued: the 13.4 mag galaxy NGC 1038 in Cetus, located 27' northeast of NGC 1032. Herschel noted: “Suspected, may be 2 small stars in the parallel.” This is the first of 13 uncatalogued objects, seen in 1786 (Table 2-41). On 4 February (sweep 522), he wrote: “Very faint, very small, 240 left it doubtful, and with long looking rather disproved it.” This is the 12.9 mag lenticular galaxy MCG -1-35-7 in Virgo. The other objects were discovered at Slough (from 18 October on with the front-view).

1786	Sw	Object	Con	V	Type	Description
1 Jan.	505	NGC 1038	Cet	13.4	Gx	suspected, 2 stars?
4 Feb.	522	MCG -1-35-7	Vir	12.9	Gx	very faint, very small, doubtful
20 Sep.	594	IC 4996	Cyg	7.3	OC	clustering stars
21 Sep.	598	NGC 7063	Cyg	7.0	OC	clustering large stars
30 Sep.	607	NGC 1128	Cet	14.5	Gx	small stars with suspected nebulosity
18 Oct.	619	King 17	Aur	14.0	OC	considerable patch of very small stars
26 Oct.	626	UGC 2272	Aqr	13.8	Gx	star 8 or 9 mag with an extremely faint nebulosity
26 Nov.	638	NGC 1449	Eri	13.4	Gx	suspected two more following [NGC 1441]
26 Nov.	638	NGC 1451	Eri	13.4	Gx	suspected two more following [NGC 1441]
28 Nov.	640	NGC 1603	Eri	13.8	Gx	suspect one south following [NGC 1611]
11 Dec.	645	IC 257	Per	12.6	Gx	very faint stars mixed with very faint nebulosity
26 Dec.	667	Cr 115	Mon	9.2	OC	clustering stars
27 Dec.	671	NGC 3910	Leo	12.8	Gx	extremely faint, extremely small, suspected

Table 2-41: Uncatalogued Herschel objects of 1786, most of them are faint galaxies (see also Table 5-5).613

On 2 January (sweep 508), Herschel discovered the galaxy pair NGC 4227/29 (II 518/19) in Canes Venatici. The components are 2.5' apart. In the same sweep, he observed the cometary galaxy NGC 4861 (IV 30), already found on 1 May 1785: “A star with a very faint milky ray to the north following; about 2 or 3' long; it almost reaches up to another star in that direction. The star with the ray, is situated about the middle of the quartile, of which that star, to which the ray is directed is the north following.” In sweep 510 on the 18th, Herschel noticed that the star 42 Ori, just 35' north of M 42, is involved in faint nebulosity. The object was catalogued as ‘large nebula’ V 30 (NGC 1977) and seen again on 28 November (sweep 640). On the 27th (sweep 512) “α Canis minoris [Procyon] passed, but I took it not account of its brightness.” In the same night (sweep 513), the 11.8 mag edge-on galaxy NGC 3495 (III 498) was found; it is only 10' east of the 4.8 mag star 58 Leo.

On 29 January, Herschel made some tests with the new 'polar distance clock', comparing its PD value with that given by the Bird quadrant.[614] In the next night (sweep 516), the faintest object of the year was perceived, the 14.6 mag galaxy NGC 1516 (III 499) in Eridanus. Shortly after, he encountered one of the brightest: "Rigel passed; but on account of its brightness I was obliged to take the eye from the telescope." Of course, in such cases he was warned by Caroline, monitoring the celestial situation with the *Atlas Coelestis* on her desk. The zone catalogue of Flamsteed stars was not helpful for this task, because the observed stars normally were not in a common PD zone. For instance, due to the sweep breadth of 2.2°, the three stars seen before Rigel (39, 47 and 69 Eri) are in different zones (101°, 98° and 99°). On the 31st, Rigel was again in the field, but now William resisted its light, seeing the bright star "beautifully defined and the small star very strong and steady. I exposed my eye by slow degrees to the light of Rigel on purpose to view it well".[615] At the end of January, a new bell mechanism was applied:

I added an improvement to the Bell machinery, which influence the truth of the polar distance. By making the settable part to be within the reach of the workman; I can immediately elevate the sweep or depress it, without using the micrometer motion under my hand or the great motion at the bottom; the advantage of this is that the same rope being employed no alteration of this is that the accuracy of the observations will be occasioned. This change of zero I find my account to as much as 2 degrees higher or 2 degrees lower without any material inaccuracy much more may it be safely used for one two or three turns of the handle.

The night of 1 February was stormy, but the telescope remained steadfast: "The whole sweep very stormy weather; and yet it seems my AR has stood very well, no observation deviating more than 3" from the mean correction." Nevertheless, some remarkable objects were found. The first, seen in sweep 518, is 13' north of the 3.9 mag star ν Eri: the 12.7 mag edge-on galaxy NGC 1618 (II 524). The "much extended nebula" forms a trio with the edge-on galaxies NGC 1622 (12.5 mag) and NGC 1625 (12.3 mag), building a 17' long chain. Although these two would be easy objects for Herschel, they were missed due to the sweep path (ν Eri was not seen either).[616] The sweep must have been boring, for nothing happened

for 32 minutes.[617] Then Herschel discovered a double galaxy (2.8'): NGC 1682/84 (II 527/28) in Orion. Next, NGC 1788 (V 32), a large reflection nebula in Orion was seen: "Considerably bright, very near and south following a bright star, milky, considerably large, the milkyness diffused and vanishing." The three 'large nebulae' in Orion, catalogued as V 33–35, are mysterious. Herschel wrote about V 33: "I suspect diffused extremely faint nebulosity. I cannot verify it." There is nothing at his position. Thus, the object, catalogued as NGC 1908 by Dreyer, has status 'not found'. The same applies for V 34: "ε [Ori] passed, and I am pretty sure is involved in nebulosity, unequally diffused." Although the object was catalogued as NGC 1990 and later called 'ε Orionis Nebula', there is nothing around the 1.7 mag star in the centre of Orion's belt.[618] Then NGC 2024 (V 28), found on 1 January, was seen again. Soon followed V 35, located by Herschel by no less than six positions: "I am pretty sure the places of which these are the boundaries are all full of diffused Milky Nebulosity; but notwithstanding I used every means of ascertaining it by motion of the telescope, my range was neither far enough, nor sufficiently quick to put it beyond doubt." After closing the sweep, he added: "Left off and tried to verify the nebulosity, but could not succeed for want of more light." V 35 is one of his 52 'diffused milky nebulosities', published in 1811 (see section 4.2.1). Dreyer did not enter the obscure object in the NGC. In the next sweep of the night (519), Herschel 'found' M 48 in Hydra, not knowing that the cluster was already seen on 8 March 1783, checking Caroline's discovery. Now it was catalogued as VI 22: "A beautiful cluster if stars, considerably rich, and pretty much compressed 10 or 12' diameter. The stars are nearly of a size, white and pretty large."

On 10 February, Herschel turned the telescope a second time to the north by the 'round motion'. In contrast to the previous missions (sweeps 389–392 on 17 March and 4 April 1785), the telescope now looked 'under the pole'. Only two 6th mag stars in Draco, missing in the *Atlas Coelestis*, were seen. The sweep at an elevation of about 30° was 'not registered' and not numbered. On the 15th, the view to the north was continued with sweep 523, having a large breadth of 4.6°. A spectacular object was found about 8:15 pm, 28° above the horizon:

Very bright, about 35" diameter. A planetary disk, but very ill defined edge; the center of it rather more luminous than the rest. With long attention a very bright well defined round center becomes visible. This seems to be a nebula that connects my former planetary ones with two other sorts; viz with those that are very bright in the middle and suddenly grow more diluted; and with those that have a bright central star, or nucleus and a milky chevelure.

Herschel has discovered the Cat Eye Nebula NGC 6543 (IV 37), shining at 8.1 mag. Obviously, the 11.4 mag central star was perceived, shown in the sketch (Figure 2-116).[619] Sweep 523 was terminated already at 8:25 pm; a second one started at 10:10 pm. What happened in the 1¾ hours in between? The telescope was rotated back to the south direction, being ready for an early start the next night (it was one day after Full Moon).[620] Although the second sweep (524) of the night lasted only 10 minutes, Herschel observed the open cluster NGC 2509 (VIII 1) in Puppis, found in sweep 35 of 3 December 1783.

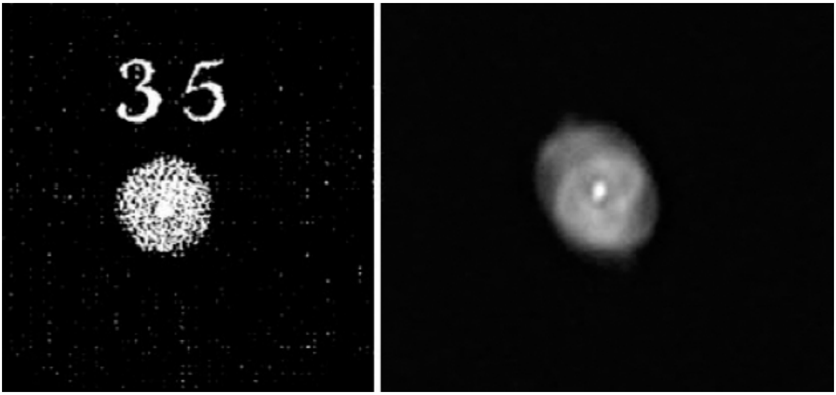


Figure 2-116: The Cat Eye Nebula NGC 6543 in Draco was found on 15 February 1786. Herschel's sketch shows the 11.4 mag central star. The 8.1 mag planetary nebula has a diameter of 20".

In the next night (16 February), Herschel started at 6:50 pm with sweep 525. Only known objects were viewed: the double star III 90 and the open cluster NGC 1896 (VIII 4), located in Auriga and Taurus, respectively.

The next interesting object was found on 24 February (sweep 529), the reflection nebula NGC 2182 (IV 38) in Monoceros (see Figure 2-67): "A considerable star very faintly affected with milky chevelure." It was followed by "A star of a deep garnet colour, about 9 m." Listed as U^{637}, this is RY Mon, shining at 7.5 mag in maximum and having a large colour index of B-V = 4.4 mag. The star is the first of three 'garnet stars' found in 1786 (see Table 2-11); the others are U Hya and W Hya (U^{657}), seen on 19 and 28 March (sweeps 541 and 550). The former is pretty bright (4.8 mag); it was viewed again in sweep 997 (7 March 1791). The night of 24 February (sweep 532) also brought a fine edge-on galaxy and a pair, both in Virgo. The single is NGC 5746 (I 126), described as "extremely bright, much extended in the parallel, 8 or 9' long". The galaxy has 10.3 mag and axis ratio of 6. The pair is NGC 5845/46 (III 511, I 128) with 12.5 and 10.0 mag, 7.3' apart. Herschel wrote: "Very bright, pretty large, brighter middle. With one preceding just H.F. [half field]; and 5' more north and very faint, round. It was exactly in the circumference when I took the great one; but below the parallel." He added: "I saw also a third small one preceding." But this is NGC 5839 (II 541), already found in the former sweep path.[621]

On the 28th (sweep 550), Herschel saw the globular cluster M 68 in Hydra for the first time: "A beautiful cluster of very compressed stars, irregularly formed but chiefly round. There are very few scattered stars about it; all the stars red, near 3' broad and about 4' long."

On 2 March, Herschel made a "trial for sweeping in the zenith", but terminated after 10 minutes: "My apparatus not being completed, I continued no longer; but find it will do well." On the 10th he wrote: "I exchanged the machinery at the bottom of the telescope, (which was moved by a rope, and pinned fast afterwards) for a bar and pinion, with an additional wheel pinion: there is also added a bar index which shews the place where the telescope is to be situated at any given altitude or zenith distance." The 'bar motion' existed from the beginning, installed to shift the bottom end of the tube towards the centre of the stand (see Figure 2-7). However, it hadn't worked properly at first. The revised mechanism was eventually applied in December, reaching high elevations.

On 3 March (sweep 536), Herschel sketched the elongated 11.1 mag galaxy NGC 4818 (II 549) in Virgo. On the 4th an interesting pair of 12th mag galaxies in Crater was found: “Two, stellar, very faint, very small. A considerable bright star is situated between them, but about 1' south of the line that joins them. 240 shewed the same.” The companions, NGC 3636/37 (II 550/51), are 4' distant; the star between them has 6.5 mag. The nice ensemble is located 1° northwest of ε Crt. NGC 3636/37 and NGC 4818 are shown in Figure 2-117.

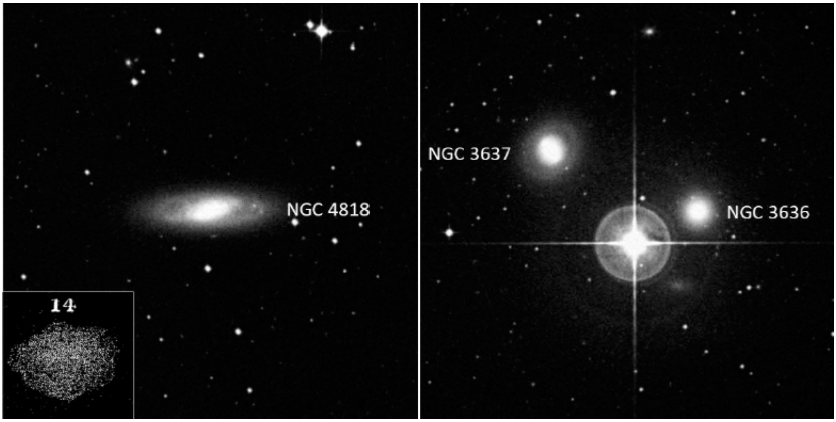


Figure 2-117: Left: the 11.1 mag NGC 4818 in Virgo, sketched on 3 March 1786 (the elongation was not noticed). Right: on 4 March, Herschel discovered the nice pair NGC 3636/37 (12.4 and 12.7 mag) in Crater with a nearby 6.5 mag star.

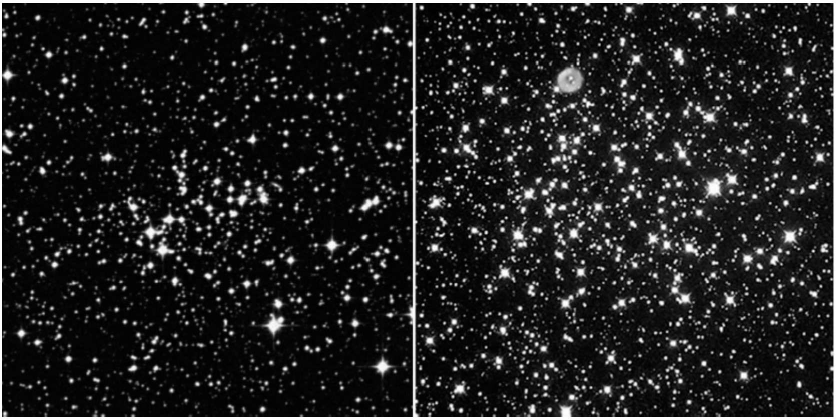


Figure 2-118: Puppis objects, found on 19 March 1786. Left: NGC 2425 is (like M 103) a rare case of an elongated open cluster. Right: the planetary nebula NGC 2438 is 6' north of the M 46 centre – a unique pair (image sizes 10' and 20').

The night of 19 March brought several highlights. The bright open cluster M 47 in Puppis was seen in sweep 540, though not identified. Herschel catalogued the Messier object as VIII 38. Two minutes later "a patch of stars about 5' long and 2' broad" was found 34' southeast (Figure 2-118). This is the open cluster NGC 2425 (VIII 87). However, it remained uncatalogued until sweep 1034 on 8 March 1793 (there is no hint to the earlier observation). Shortly after and only 50' east, M 46 in Puppis was seen for the first time in the 18.7-inch. Then Herschel had a spectacular view: "A round pretty bright resolvable nebula with the preceding cluster [M 46], almost of an equal light throughout about 2' diameter, has no connection with the cluster; which is every where free from nebulosity." This is the 10.8 mag planetary nebula NGC 2438 (IV 39), located only 6' north of the cluster centre (Figure 2-118).[622] The unusual pair was again seen on 8 March 1793 (sweep 1034). In the second sweep of the night (541), the telescope pointed to Hydra, where the 11.7 mag galaxy NGC 2855 (I 132) was discovered. About 45 minutes later, NGC 3145 was seen: "very faint, round, small, 7 or 8' south preceding λ Hydrae". The star has 3.6 mag. It is remarkable that the 11.7 mag galaxy was catalogued as 'very faint nebula' III 518. Obviously, the star outshined it. A little later, Herschel found "a garnet coloured star, 6 to 7 m". This is U Hya; the variable red star can reach 4.9 mag. It was observed again on 7 March 1791 (sweep 997); see Table 2-11.

Stars also played a role in sweep 546 on 25 March. The galaxy NGC 4770 (III 525) in Virgo is 12' west of the 4.8 mag star ψ Vir. Next, Herschel discovered the unequal pair NGC 4781/84 (I 134, III 526); though 5.6' apart, the companions were seen in different fields (connected by the 'side motion'). Later "Spica passed, but it was too bright to have its transit taken; unless I would have stopped long enough gradually to admit the light."

The final sweeps of March were made on the 27th (547, 548) and 28th (549, 550), yielding 12 new objects, the last that were found at

Clay Hall. Among them are two pairs, seen in sweep 548. The first is NGC 3661/67 (III 530/31) in Crater (distance 9.8'). The second, NGC 4782/83 (I 135/36) in Corvus, is much brighter and extremely close (52"): “Two, both considerably bright, round, considerably small, much brighter middle, in the direction of the meridian, nearly with 1' of each other, and the chevelure mixing.” This is a contact pair of giant elliptical galaxies, forming a dumbbell (see Figure 2-101 and Table 2-28).[623] Shortly after, Herschel saw a dubious object in Corvus: “Suspected, a pretty bright star, with a seeming brush to the north preceding, may be a small nebula close to it; but there was no time to verify it.” Catalogued as IV 40 (NGC 4804), this is only a pair of stars (Table 2-26, Figure 2-92).[624]

2.5.2. Move to Slough and Caroline’s second zone catalogue of Flamsteed stars

Herschel looked for the right place to errect the 40-ft reflector. Obviously, the space at Clay Hall was too small. On 25 March Herschel wrote:[625] “Looking for a proper situation to erect the 40 feet telescope I fixed upon a house and garden at Slough, to which I removed at Lady day.” Slough is a small village about 6 km north of Clay Hall. At the end of March and beginning of April, the Herschels carried out the move. Their new home at Slough was in the Windsor Road; later it became a popular place due to the 40-ft ‘Herschel Telescope’ (Figure 2-119).

Figure 2-119: The small village Slough and its main attraction (see Figure 2-3). From the Bath Road (now High Street), connecting London and Bath, the new landmark was easily visible for travellers. Nearby Upton was the home of Herschel's future wife and also the place of his grave.

For 3 April we read: "The [20-ft] telescope removed to Slough and neither my time, nor meridian ascertained." Anyway, sweep 551 was started at 11:30 pm, inspecting parts of Corvus and Hydra. The observation lasted about one hour. The next sweep (552) was made on the 15th. A known nebula was seen in Leo: NGC 3611 (II 521), a 12.2 mag galaxy, found on 27 January. However, both sweeps are indicated 'Not to be registered'. On 16 April we read: "By equal altitudes clock 20,5" too slow. I moved the telescope (by quadrant) ½ degree more west." Obviously, there were still problems with the setting.

Two regular sweeps were eventually performed on the 17th (553, 554), lasting 3.5 hours without any break. 11 objects were found, a good debut at Slough. However, there were problems with the newly employed workman. When re-observing the pair NGC 4261/64 (II 139/40) in Virgo, Herschel wrote: "Two, ill taken by the blunder of the person at the handle; who is not acquainted with

the business." And shortly after, he noted: "A stop occasioned by the same blundering person."[626] However, between the two events, he discovered a spectacular quartet of nebulae in Virgo: "Four, the time and number is that of the last. They are scattered about." He catalogued them as 'faint nebulae' II 568–71. The members are the 12th mag galaxies NGC 4268/70/73/81, just fitting into the field of view (Herschel's four galaxy quartets are listed in Table 2-29 and shown in Figure 2-104). Both John Herschel and Dreyer were confused about the situation. Shortly after, a remarkable nebula was seen in Virgo, catalogued as I 139. The 9.7 mag galaxy was seen again in sweep 558 on 30 April: "extremely bright, very bright nucleus, round, 6 or 7' diameter". William never recognized that this was M 61.[627]

On 22 April, Charles Blagden, Joseph Banks and the illustrious Lord Cavendish were invited to perform a sweep (Figure 2-120).[628] Though it was a regular observation in Leo it was not numbered (breadth 2° 15'). A similar event had already happened on 6 May 1785, when v. Brühl, Aubert and v. Zach joined a sweep.

Figure 2-120: Guest observers at Slough on 22 April 1786: Charles Blagden, Joseph Banks and Lord Cavendish.

The star party started at 8:30 pm in "strong twi-light". The first target was the galaxy trio about M 105; Herschel wrote: "After some time looking, I perceived the 3rd [NGC 3389] which is more faint, Dr Blagden saw it also". This implies that he and Blagden were observing together (for about one hour). Then Banks, sweeping for 30 minutes, saw the 10.9 mag galaxy NGC 3593 (I

29). Lord Cavendish took over and viewed the 10.8 mag galaxy NGC 3810 (I 21). 15 minutes later, Banks was at the eye-piece again, viewing the 11.8 mag galaxy NGC 3968 (II 162). Herschel noted: “He perceived it in the field just when my sister said there it is.” All objects were well-known since the spring of 1784 and Caroline had them in the ‘Register of Nebulae’. Banks actually made a star gage. The sweep was terminated by haze and clouds at 9:45 pm. There are questions. How could the four observers take turns taking the chair (at an elevation of 52°) and continuing the sweep without wasting too much time? How could Blagden and Herschel observe together and take turns using the eyepiece? Maybe the chair was wide enough or it was enlarged. The drawing (Figure 2-24) does not suggest it.[629]

April ended with nice pairs in Virgo. On the 29th, NGC 5382/86 (III 546/47), distance 5', was found (sweep 557). In the next night (sweep 558), Herschel saw three pairs, shortly one after another. The first is NGC 5560/66 (II 579, I 144), distance 5.3'; here two edge-on galaxies are oriented perpendicular to each other.[630] A similar case is NGC 7332/39 in Pegasus, discovered on 19 September 1784 (sweep 278); both are shown in Figure 2-74.

The second pair, only 43' south, was brighter and closer (2.8'): NGC 5574/76 (I 145/46). The third, 2° east of the former, has only 2' distance: NGC 5636/38 (II 580/81). The night also brought an object, seen “considerably bright, just north preceding a pretty bright star, and joining it so as to appear like a brush to it”. This is the 11.4 mag face-on galaxy NGC 4900 (I 143), only 43" northwest of an 11th star – a remarkable view (Figure 2-121, Table 2-26).

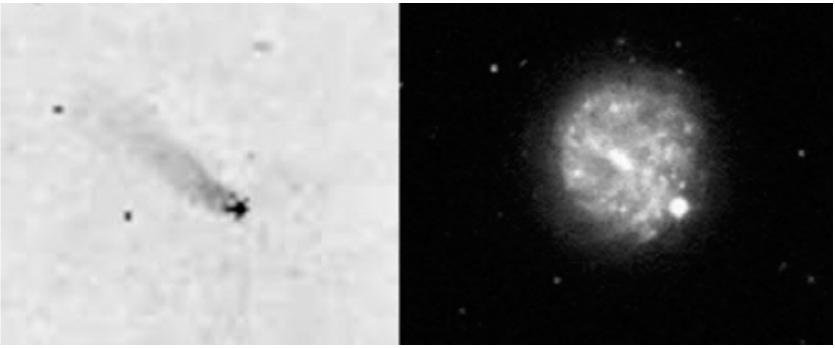


Figure 2-121: A curious combination was found on 30 April 1786: the galaxy NGC 4900 in Virgo with a star superimposed at its edge.

In the night of the 30 April, two sweeps were performed. In the first (558), 27 objects were observed in Virgo, 14 were new. After a one-hour break, Herschel continued with sweep 559. The first observation, made in Scorpius, is interesting: "A small cluster of very small stars, pretty rich; coming just from the light, I saw it but imperfectly, about 5 or 6' long and near 4' broad, in form of a parallelogram. Five minutes after it was past, I returned to it, and saw it very well." He had found a small star group at the eastern edge of the field of view; it was catalogued as VII 29 (NGC 5998), 1.7° northwest of ρ Sco (later seen in the sweep and used as reference star). For a better view of the cluster, he "returned to it". What does this mean?

The case is a good example to explain main features of Herschel's sweeping process (Figure 2-122).[631] The following schedule results from Caroline's sweep record. The sidereal clock showed $15^h\ 37^m\ 27^s$ when the 'small cluster' VII 29 was seen. This also marks the start (top) of sweep 559 at AR 15 37 53 and PD 117 57 in Scorpius. The open cluster was not seen in the centre of the field of view, but at the southwestern edge (small circle): an offset of -36^s in AR and +2' in PD is noted (it was needed to determine the correct AR and PD). The sweep had a breadth of 2° 25'. Herschel did not rest at this position but prompted the workman to move the tube down in a constant manner. When reaching the bottom of the sweep (at PD 120 24) the lower bell rang and the direction was changed. To return to the cluster, the tube must reach the top PD again. The whole path (down & up) had to be covered in "five minutes". This would imply that 2.5^m were needed to cross the breadth of 2° 25' (this is a reasonable sweep speed of 1° per minute). When the top level was reached again (indicated by the bell), Herschel could return to his star cluster by the 'side motion'. Meanwhile the sky has moved by 5^m. This corresponds (at that declination) to an angle of 66', which is about four fields of view. The mechanism allows such a shift to the west and William could now study the cluster in detail (the description refers to this second visit). How much time did he have? The reference star ρ Sco should be his next object (foreseen by Caroline). It was actually observed 1.6^m after he had

reached the top level (to return to the cluster). Assuming a sweep speed of 1° per minute for the down motion to the star, lying 36' more south, it took about 0.6^m to reach the place. This implies a time gap of 1^m. This is a reasonable interval to reach the cluster, its study and the return to the meridian to continue the sweep.

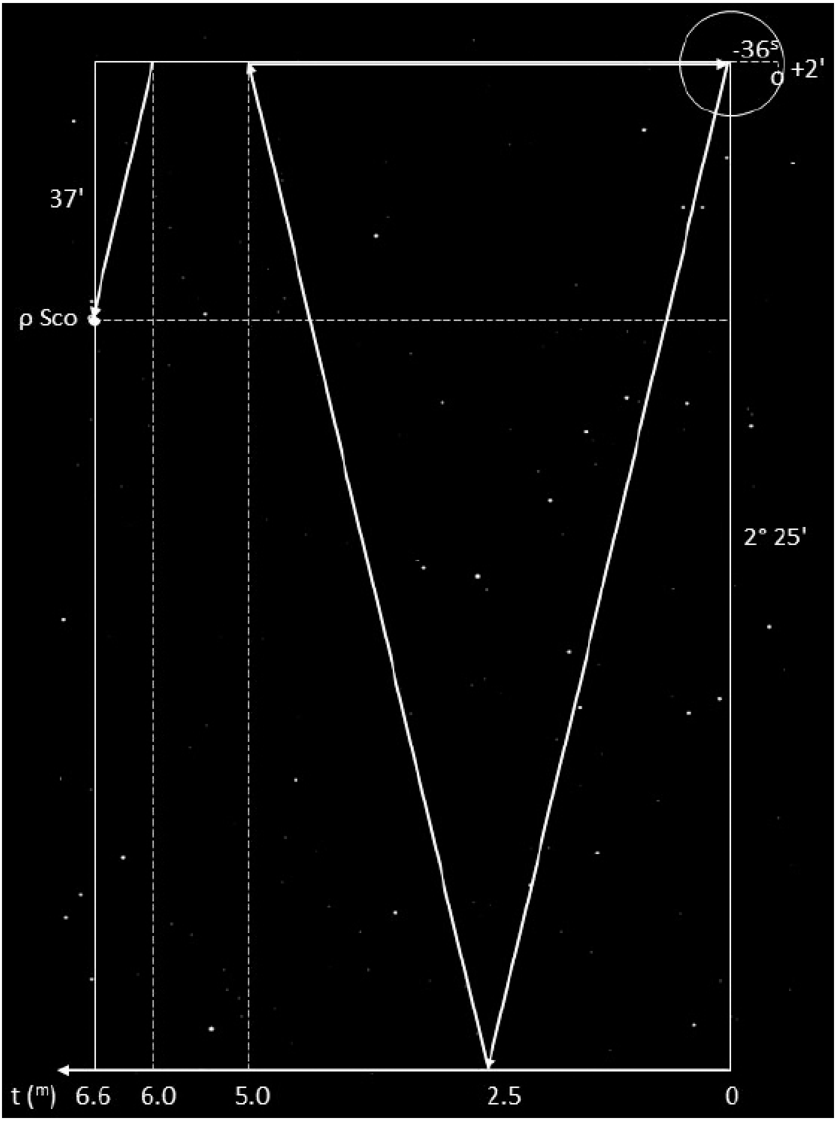


Figure 2-122: Paths in sweep 559 (see text).

On Thursday morning, 4 May, Herschel watched his first Mercury transit: “5h 42' Mean time. I saw Mercury on the disk of the Sun. It appeared as a very black, round spot. 7 feet reflector power 278. I could only have a single glimpse of it between clouds.” During the transit he used powers up to 1180, measuring the size of the planet’s disk. He finally wrote: “Most of the observations were made without a red glass, the Sun being sufficiently shaded by clouds.” A second transit was seen on 9 November 1802 (see Table 2-54).

The night of 26 May (sweep 566) started with a surprise at 10:15 pm: “My sister swept by way of practise to myself of booking for her.” With 14° tube elevation, Caroline’s position was quite comfortable (breadth 2.2°). The sweep in Libra lasted until 10:39 pm; only 12 Lib was observed (“a fine red star”). Two minutes later we read that William “began now to sweep, the twilight being pretty well gone off”. It is astonishing that the change was done so quickly. The globular cluster M 80 in Scorpius was observed. Later William saw “A double star with extensive nebulosity, of different intensity; about the double star is a black opening, resembling the nebula in Orion on a small scale.” The star was catalogued as N40 and the nebula as IV 41. A minute later, he noted: “A very coarsely scattered cluster of stars. The 20th of the Connoiss. des temps.” The nebula is the Trifid Nebula M 20. The ‘cluster’, seen about 27' northeast, is not a Messier object. It could be M 21 (40' northeast), but this open cluster was seen right after (for the first time with the 20-ft): “A rich cluster of large stars. The 21st of the Connoiss. des temps.”[632] Two other clusters were found shortly after, already in “strong twilight”: NGC 6568 (VII 30) and NGC 6583 (VII 31).

In sweep 568 on 28 May, Herschel had a problem with two anonymous guests: “The time was disturbed by the weight of two Gentlemen who occasionally mounted into my seat.” This implies that he still used the observing chair, installed at the side of the tube to reach the eye-piece at the Newtonian focus – but why two men? The second sweep (569) of the night brought an interesting planetary nebula, though not entered in class IV: NGC 6445 (II 586). The small 11.2 mag object is located in Sagittarius. Shortly after and 2° northeast, Herschel saw the open cluster M 23. The sweep had started with the globular cluster M 9 in Ophiuchus.

On 3 June (prior to sweep 572), Herschel wrote: "Lord Effingham, another gentleman & Mr. Arnold saw the 5th Nebuleuse of the Connoissance des temps [M 5 in Serpens]; in the 7 feet reflector; afterwards in the 20 feet."[633] The sweep brought a new globular cluster: NGC 6426 in Ophiuchus, 1.3° northeast of M 9. It was not resolved and thus catalogued as 'faint nebula' II 587. Five sweeps (573–577) were made until 28 June, finding one object in Hercules, the 11.7 mag galaxy NGC 6548 (III 555), and four clusters in Sagittarius, nothing spectacular.

2.5.3. William's absence and Caroline's success – the 1st comet

The observation, made on 28 June 1786, was the last before William and Alexander started a journey to Hanover on 3 July. There they met their brothers Dietrich and Jacob (the latter kindly offered his home).[634] Still in July, William and Dietrich brought a 10-ft / 9-in reflector to Göttingen Observatory (a present of King George III). William and Alexander returned on 16 August. What had Caroline done in their absence? On 12 July she wrote:[635]

I put paper in a press for a Register and calculated for Flamsteed's catalogue. Mem. When Flamsteed's catalogue was brought into zones in 1783, it was only taken up to 45° from the Pole, the apparatus not being then ready for sweeping in the zenith. By July 23rd the whole Catalogue was completed all but writing it in the clear, which at that time was a very necessary provision, as it was not till the years 1789 that Wollaston's Catalogue made its appearance. Many sweeps nearer the Pole than the register of sweeps, which only began at 45°, being made, it became necessary to provide a register for marking those sweeps and the nebulae discovered them.

Indeed, on 23 July we read: "Finished calculating for Flamsteed's Catalogue." Caroline soon wrote down the result.[636] The PD now ranges from 0° to 126°. The new table gives the star position (AR, PD) for 1690, the precession for a period of 72 years and the magnitude, both taken from the *British Catalogue*. Her first version of the zone catalogue, made in 1783, lists only stars with PD ≥ 45°, giving positions for 1690 and the annual precession.[637] It is

astonishing that Caroline still used the Flamsteed equinox, though, since the beginning of 1785, the ‘equinox of the date’ was applied. So, she must calculate every star position individually. However, to minimize the effort, she used a trick, mentioned on the last page of her second version of the zone catalogue: “Multiplier for 1785 1,319444.”[638] This decimal value is equal to 95/72. Thus, Caroline simply multiplied the pression of the *British Catalogue* by this factor. The only problem: Flamsteed’s right ascension is measured in degrees instead of hours. Thus, the factor 1/15 has to be applied in addition to get the AR precession in minutes and seconds.[639] On 11 December (sweep 644), the first observation with PD $< 45°$ was made ($\delta > 45°$, $E > 83°$). On 23 July, Caroline also had noble guests: “Prince Charles (Queen Charlotte’s brother) Duke of Saxe-Gotha and the Duke of Montague were here this morning. I had a message from the King to show them the instruments.”[640]

What about observing? Caroline’s last nightly session was on 9 April 1785 at Datchet. Unfortunately, at Clay Hall she hadn’t found time for observing. But now, and in the absence of her brother, the conditions were better:[641]

At Slough, better arrangements were made for her. The rooms connected with the stables had been converted into a dwelling house; the harness room became a writing room and the room or rooms above, Caroline says, were now ‘Our Observatory’. A small staircase led out on to the roof, which was flat, and here the small Newtonian sweeper was installed. To assist her in recording the time of her observations, her brother Alexander had made for her a sort of metronome which ticked seconds loudly; this instrument was known in the family as the ‘Monkey Clock’.[642]

Caroline’s ‘Observatory’ was the cottage near the main house (Figure 2-123); later it actually became her home. She could place her telescopes on the flat roof (the large sweeper was erected there on 13 May 1790). With no railings, it was a rather unsafe place in the dark, especially in winter.

Figure 2-123: John's camera lucida drawings, made about 1840 at Slough. Left: The main house and Caroline's cottage (flat roof). William's 18.7-inchwas at the place marked 'x'; the 40-ft was still present. Right: John's 18¼-in at the place of his father's reflector in front of the cottage (Caroline's room with the desk was that left of the door); compare Figure 2-119.

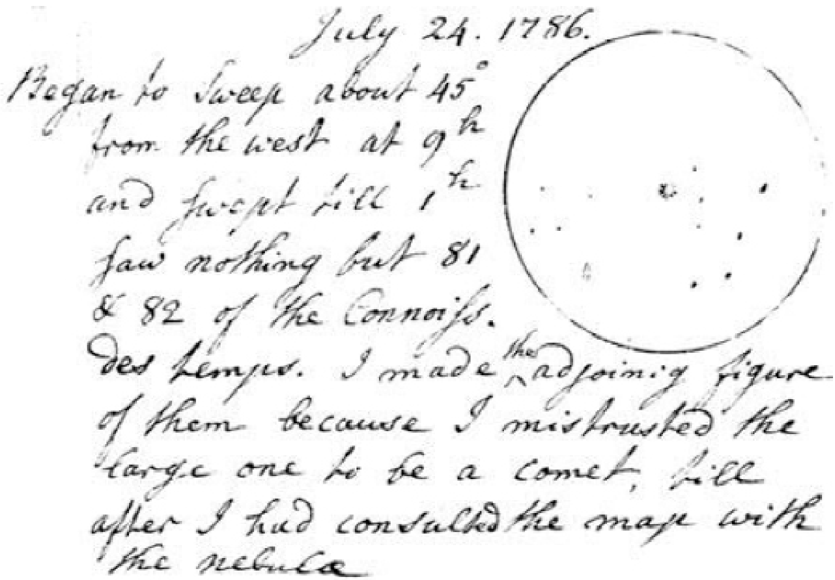

July 24. 1786.
Began to sweep about 45° from the west at 9h and swept till 1h saw nothing but 81 & 82 of the Connoiss. des temps. I made the adjoining figure of them because I mistrusted the large one to be a comet, till after I had consulted the map with the nebula

Figure 2-124: Caroline's observation of the galaxy pair M 81/82 in Ursa Major, made with the small sweeper on 24 July 1786 at Slough.

On 19 July 1786, the small sweeper was activated: "At $10^h\,45'$ began to sweep from υ Ursa major. With perpendicular sweeps from the horizon to the zenith. After I had swept upwards of 60° left off, clouds coming." And a bit later: "I used the lower power [24 ×], and saw all the small stars very distinctly; but saw no nebula, nor

anything remarkable sweeping the above place took about two hours. The finder not in order.” On the 24th Caroline observed M 81 and M 82 in Ursa Major; a sketch was made (Figure 2-124). However, M 82 was first mistrusted to be a comet – but such an object would soon follow!

The observation of 1 August, made Caroline a recognized astronomer (Figure 2-125): “9h 50' I saw the object in the center of fig. I like a star out of focus while the others were perfectly clear, the preceding star is very faint but the weather is hazy, and in a clearer night undoubtedly some more will be visible.” She wrote in her *Book of Observations*: “this evening I saw an object which I believe will prove to morrow night to be a comet”. The object was seen in eastern Leo, about 12° above the north-western horizon; the brightness was 3.2 mag. The observation on the 2nd showed a motion – it was indeed a comet! More sightings followed until 11 September; the comet then was at the Corona Borealis/Serpens border with a brightness of 7 mag.[643]

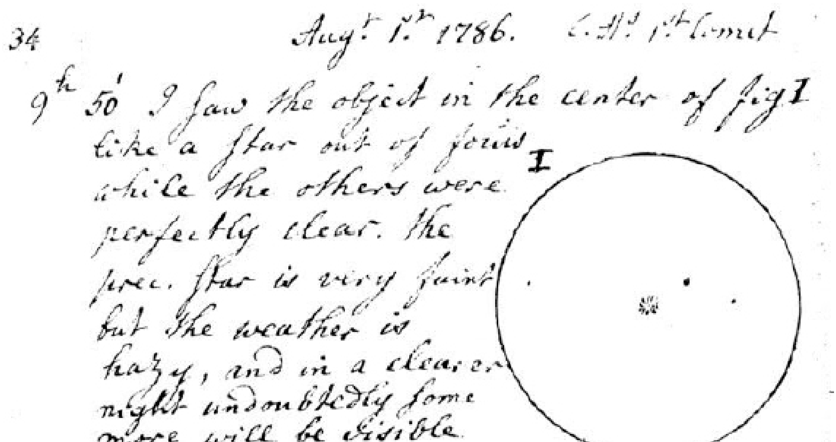
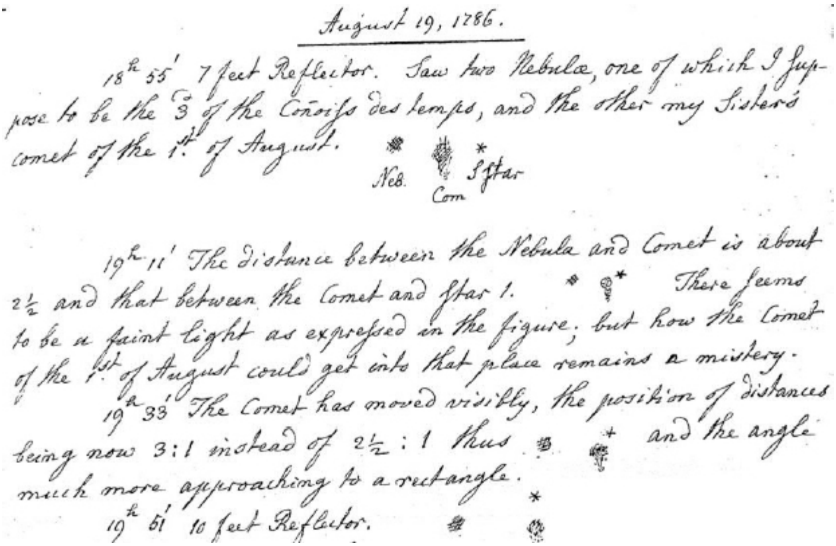


Figure 2-125: Caroline’s discovery of her first comet on 1 August 1786, using the small sweeper. The object was seen in Leo.[644]

On 19 August, William, back from Hanover after 52 days, saw Caroline’s comet for the first time:[645] “18h 55' 7 feet reflector. Saw two nebulae, one which I supposed to be the 3rd of the Connoiss. des temps, and the other my sister’s comet of the 1st August.” A sketch was made (Figure 2-126). The 5th mag object was 7'

southwest of the globular cluster M 3 – a spectacular celestial pair! An hour later, the motion was obvious in the 10-ft.


August 19, 1786.

18h 55' 7 feet Reflector. Saw two Nebulæ, one of which I suppose to be the 3 of the Conoiss des temps, and the other my Sister's comet of the 1st of August.

Neb. Com S star

19h 11' The distance between the Nebula and Comet is about 2½ and that between the Comet and star 1. There seems to be a faint light as expressed in the figure; but how the Comet of the 1st of August could get into that place remains a mistery.

19h 33' The Comet has moved visibly, the position of distances being now 3:1 instead of 2½ : 1 thus and the angle much more approaching to a rectangle.

19h 51' 10 feet Reflector.

Figure 2-126: William's first observation of her sister's comet was made on 19 August 1786. The object was near M 3 in Canes Venatici. The nearby 'small star' has 11 mag.

After seven sweeps, marked 'Not to be registered' (due to clouds or haze), a regular one (581) was made on 4 September. The 'bright nebula' I 151 was discovered in Pisces, the 10.2 mag galaxy NGC 524.[646]

The summer at Slough was used for the construction of the 40-ft. Caroline wrote:[647]

A workman for the brass and optical parts was engaged, and two smiths were at work throughout the summer on different parts for the forty-foot telescope, and a whole troop of labourers were engaged in grinding the iron tools to a proper shape for the mirror to be ground on (the polishing and grinding by machines was not begun till about the end of 1788). These heavy articles were cast in town, and caused my brother frequent journeys to London, they were brought by water as far as Windsor. At Slough no steady out-of-door workman for the sweeping handle could be met with, and a

man-servant was engaged as soon as one could be found fit for the purpose. Meanwhile Campion assisted, but many memorandums were put down: 'Lost a neb. by the blunder of the person at the handle.' If it had not been sometimes for the intervention of a cloudy ore moonlight night, I know not when my brother (or I neither) should have got any sleep; for with the morning came also his workpeople.

The garden and workrooms were swarming with labourers and workmen, smiths and carpenters going to and from between the forge and the forty-foot machinery, and I ought not to forget that there is not one screw-bolt about the whole apparatus but what was fixed under the immediate eye of my brother. I have seen him lie stretched many an hour in a burning sun, across the top beam whilst the iron work for the various motions was being fixed. At one time no less than twenty-four men (twelve and twelve relieving each other) kept polishing day and night; my brother, of course, never leaving them all the while, taking his food without allowing himself time to sit down to table.

The night of 20 September (sweep 594) brought Herschel's second IC object, discovered in a sweep: the open cluster IC 4996 in Cygnus. He wrote: "Clustering stars, the place taken is pretty much condensed, and contains 3 pretty large stars close together." The object was not catalogued (see Table 3-3). Shortly after, he saw the open cluster M 29 for the first time with the 20-ft. Although Herschel knew the object from two observations in 1783 with the 7-ft, he was not aware of it now, briefly writing: "Clustering large stars." The position clearly points to the Messier object. It was seen again in sweep 1027 on 15 September 1792 (and now identified): "A cluster of very coarsely scattered very large stars; not rich. No. 29 of the Connoiss." At the end of sweep 594, Herschel encountered 61 Cyg, Bessel's famous parallax star.[648]

On 21 September (sweep 599), a galaxy quartet was discovered in Andromeda.[649] The members are NGC 703/04/05/08 (III 562–565). Herschel wrote: "Four, unequal, 3 in a row, the 4th making a rectangle with them. All in a space of 2 or 3'; the one at the angular part is much larger than the others." The dense ensemble in Andromeda marks the centre of the galaxy cluster Abell 262. NGC

708 is the largest and brightest member (12.7 mag); see Table 2-25. None of the five other NGC objects, located in a circle of 25' diameter, was seen by Herschel; the sweep path was not suiting. He never returned to the place, located only 2° southeast of the large open cluster NGC 752, discovered 1783 by Caroline.

2.5.4. The 20-ft as a front-view reflector

22 September 1786 brought another trial of the front-view mode, already tested for the 18.7-inch reflector on 20 November 1783 in sweeps 29–34.[650] In a memorandum below the sweep 600 record, Herschel wrote:

I repeated some former experiments by looking into the telescope at the front, without the small reflecting mirror, and found the image as good as at the side; the light is incomparably mor brilliant, and I thought sometimes that the stars were, if not better, at least full as well defined as in the Newtonian way, so that it seems I have heretofore too hastely laid it aside. In high sweeps the position of looking is a very convenient one; and in no other situation can it be a very bad one. On the mature consideration we find that writing and often reading are generally done by looking nearly either more or less downwards and even perpendicularly on the paper or book; and yet there are things that can be done for many hours together without great fatigue.

The question is, how did Herschel reach to tube opening of the 20-ft with an eye-piece in his hand? Four years earlier, things were easier due to the front gallery, installed between the front ladders. It seems impossible, that he was able to look into the tube, while sitting on his chair at the side (see Figure 2-24). Remaining in the chair and stretching forward would be life threatening at a distance of about 2 feet. The only way to reach the tube front is by a separate ladder placed in front of the telescope. However, when considering the objects, seen in that night by the front-view, this also is a dangerous task. Herschel observed in Lacerta and Cygnus at PD 52°, implying a tube elevation of 76°. Thus, the opening was about 19 feet above the ground.[651] Why would one choose such a high position for a front-view test without a gallery? Did Herschel actually re-install the old gallery? This is unlikely. Because he

regularly swept on the chair in the former night (21 September), the time to modify the telescope was too short. Moreover, the three sweeps (601–603) of the next night (23 September), were done again ‘by the side view’. However, the main mirror must have been tilted for sweep 600, because in the next sweep it is noted that “this was swept by the side view, with a proper adjustment of the object speculum”. The Newtonian design was kept in the following sweeps (604–608), made on 25 and 30 September That all sounds rather strange!

Sweep 607 (30 September) brought a peculiar object, worth a sketch (Figure 2-127). This is the 11.7 mag galaxy NGC 676 (IV 42) in Pisces. Herschel wrote: “A star with very faint branches in the direction of the meridian, each branch about 1' in length; the star about 8.9 m [8–9 mag]; other stars of the same size are free from these branches.” There is, indeed, a 10.5 mag star. It is centrally superimposed on the edge-on galaxy; this causes the impression. NGC 676 is the first of three in a 49' long galaxy chain, oriented southwest to northeast. The other galaxies are NGC 693 (II 859, 12.4 mag) and NGC 706 (II 596, 12.5 mag). However, NGC 693, located nearly in the middle of the chain, was not seen; The object had to wait until 25 December 1790 (sweep 986). Why was it missed in 1786? The object lay just in a gap between two sweep paths.

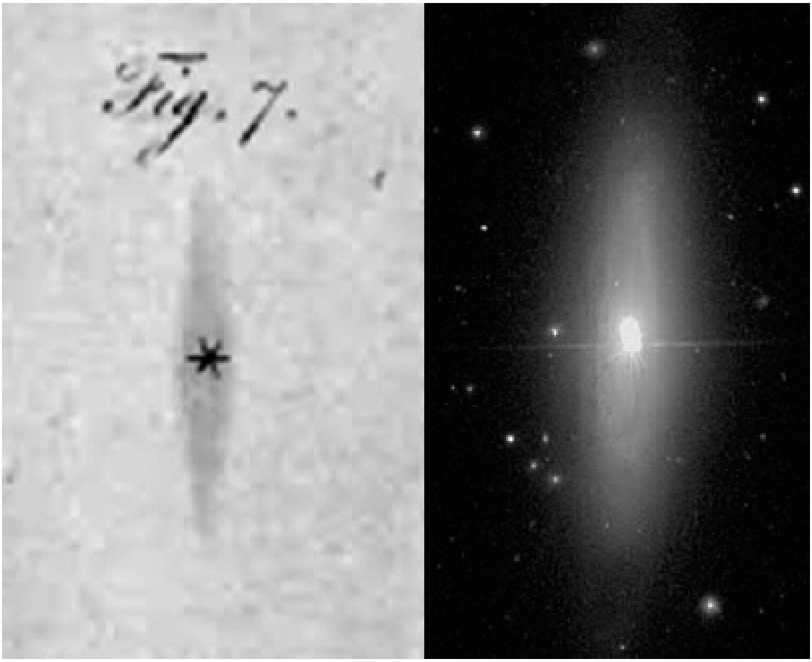


Figure 2-127: The 11.7 mag edge-on galaxy NGC 676 in Pisces is oriented north-south. It was sketched on 30 September 1786. There is a 10.5 mag star, centrally superimposed on the disk.

There was a break of 13 days until 13 October, when sweep 609 was marked ‘By the front view’. The first objects, seen with the new optical design, were already known: the globular cluster M 30 in Capricornus and the galaxy NGC 7184 (II 1) in Aquarius. Then the first find with the front-view was made: the 11.1 mag galaxy NGC 7377 (II 598) in Aquarius. No doubt, Herschel has used the period in early October to modify the telescope. This implied a front gallery (platform), stable enough to work at high tube elevations, which also meant a more massive stand. Moreover, the main mirror got a fixed tilt of 1.35°. The secondary mirror, the eye-piece holder at the side of the tube and the observing chair were removed. The front-view would become the standard until the last sweep in 1802. A slide device to hold eye-pieces was installed at the left side of the octagon tube; of course, the right eye (Herschel’s favourite) must be used, to omit any obstruction by the head.[652]

The famous drawing, showing the converted 20-ft in 1787 in the

garden at Slough, was published in February 1794 (Figure 2-128).[653] Due to the short shadow of the stand, the instrument might be oriented to the south. The quadrant is the triangular device near the top of the right ladder. However, there are some odd details: (1) There is no eye-piece holder at the tube opening. (2) The finder is attached at the top side of tube – not easy to reach from the front gallery (note the small chair). (2) Caroline's cottage or the 40-ft telescope are not shown, there are only some bushes in the background (compare Figure 2-123 and Figure 2-141).

The front-view changes the orientation in the field of view. This is mentioned in another memorandum, below the sweep 609 record: "My method of looking into the telescope as to night, is different in its effect from the Newtonian, in that it turns N and S but not preceding and following. The Nebula of Oct. 28, 1783, No. (1) for instance appeared thus (by memory) which compared to a former picture explains what I have said." The 'nebula' is the galaxy NGC 7184 (II 1) in Aquarius; a sketch was given. The field orientation depends on two factors: the optical design of the telescope and the viewing direction; Figure 2-129 shows all possible cases (using NGC 7184).[654] Due to the reflection law, they differ from the naked-eye view. Ignoring the relation between telescope and field orientation can create a lot of confusion. Relative positions or position angles will be incorrectly determined. It is astonishing how perfectly Herschel's mind immediately transformed the twisted views into correct descriptions, concerning the different directions (p, f, n, s).

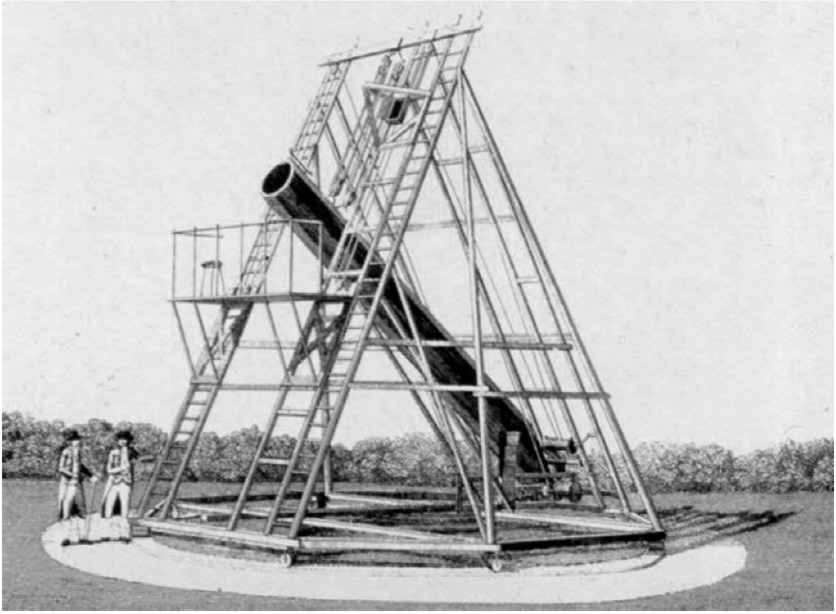


Figure 2-128: The 20-ft front-view reflector at Slough with its stable observing platform (gallery), drawn in 1787 (see text).

Direction	Mode	View	Sweeps
south	front-view	meridian	29–34, 600, ≥ 609
south	Newtonian	meridian	all other < 609
north	Newtonian	meridian, above the pole	389–392
north	Newtonian	meridian, under the pole	523
north	front-view	meridian, above the pole	several 757...1099
north	front-view	meridian, under the pole	several 1064...1112
east	Newtonian		281–285

Table 2-42: Herschel's telescope designs and viewing directions (compare Figure 2-129).

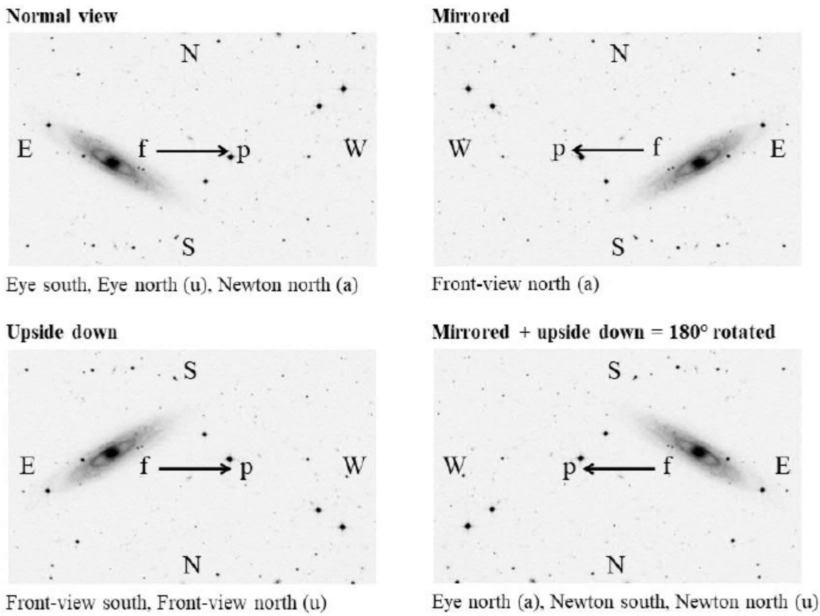


Figure 2-129: There are four possible field orientations in the meridian, realized by different configurations (instrument, direction); a/u = above/under the pole. The object is the galaxy NGC 7184 (II 1) in Aquarius.

A longer account on the front-view, summarizing the two memorandums, is given in the notes appended to the first Herschel catalogue.655 The occasion is the convincing observation of V 15 (NGC 6960), the western part of the Veil Nebula in Cygnus, on 18 October 1786 (sweep 615). Herschel wrote:

The *Front-view* is a method of using the reflecting telescope different from the Newtonian, Gregorian, and Cassegrain forms. It consists of looking with the eye glass, placed a little out of the axis, directly in at the front, without the interposition of a small speculum; and has the capital advantage of giving us almost double the light of the former constructions. In the year 1776 I tried it for the first time with a 10 feet reflector, and in 1784 again with a 20 feet one; but the success not immediately answering my expectations, it was too hastily laid aside. By a more careful repetition of the same experiment I find now, that several other considerable advantages, added to the brilliant light before mentioned, make it at least in all

cases where light is more particularly wanted; and from the experience of 30 sweeps, which I have already made with it, I may venture to announce it to be a very convenient and pleasant, as well as useful, way of observing. With regard to the position of objects, it differs from other constructions, by inverting the north and south, but not the preceding and following.

Finally, in 1787, on the occasion of the discovery of two moon of Uranus, Herschel wrote: "I was often surprised when I reviewed nebulae that had been seen in former *sweeps*, to find how much brighter they appeared, and with how much facility I saw them. The cause of it will be no other than the quantity of light gained by laying aside the small speculum, and introducing the *Front-view*."[656]

In sweep 613 on 17 October, the 11.3 mag edge-on galaxy NGC 7640 (II 600) was found in Andromeda. Then, 1.8° northwest and right on the sweep path, Herschel encountered the stunning planetary nebula NGC 7662 (IV 18), known from the eastern sweep 283 (6 October 1784). 15 minutes later, he saw the Andromeda Nebula for the first time in the meridian; the former observations in October 1784 were made 'in the east'. The small companion, M 32, was also seen. However, the view was disturbed by northern light: "The Aurora borealis is so bright even in the Zenith that it fills the field of view with light, so as to stop the sweep."[657] Sweep 614 started one hour later and was free from this 'light pollution'. Some interesting objects were found in Perseus. Two, NGC 898 (III 570) and NGC 910 (III 571), are members of the galaxy cluster Abell 347, located 45' southeast of the edge-on galaxy NGC 891 (Table 2-25).[658] 10 minutes later, the galaxy pair NGC 980/82 (III 572/73), not associated with the cluster, was discovered; the distance is 3.6'. It was followed by NGC 1275 (II 603), the dominating member of the Perseus Cluster (Abell 426). Herschel noted: "pretty bright, stellar; or a pretty considerable star with a small very faint chevelure". The object was sketched.[659] Two other members, NGC 1293/94 (III 574/75), forming a close pair (distance 2'), were seen next. The Perseus Cluster forms a 2° long chain, involving 22 NGC galaxies. He discovered only three of them (see Table 2-25) – and never returned to the interesting place.

In sweep 617 (18 October), Herschel found the 12.3 mag galaxy

NGC 7426 (III 576) in Lacerta, located 4' east of a 5.7 mag star (with a 9th mag companion), not catalogued by Flamsteed. Caroline later identified it as “37 (p) Honr. Friderices of Bode’s Cat.” The strange constellation ‘Honores Friderici’ (Glory of Frederick the Great) was introduced by Bode in 1787 to honour the King of Prussia. It is located between Cepheus, Andromeda and Cygnus. Another interesting galaxy / double star combination was seen in sweep 618 (same night): NGC 828 (II 605) and 59 And (IV 129); the 6th mag stars are 17" apart, the 12.2 mag galaxy is 12' northwest. Both ensembles are shown in Figure 2-130. Shortly after, Herschel discovered the 9.4 mag galaxy NGC 1023 (I 156) in Perseus.

Figure 2-130: Two galaxy / double star combinations were found on 18 October 1786. Left: NGC 7426 in Lacerta, 4' east of a pair (5.7 and 9.0 mag), distance 53". Right: NGC 828, 12' northwest of 59 And (6.0 and 6.7 mag), distance 17"; there actually is a nearer pair, 3' east of the galaxy (10.2 and 11.0 mag, 17") – a nice ensemble.

Sweep 620 on 24 October brought a spectacular object in Cygnus: NGC 7000, known as the North America Nebula.[660] Herschel noted: “Very large, diffused nebulosity plainly visible, between 7 or 8' long, 6' wide, and losing itself gradually.” However, he had only seen a bright part in ‘Mexico’. The object was catalogued as ‘large nebula’ V 37. He returned to it on 11 September 1790 (sweep 959): “Faint milky nebulosity scattered over this space; in some places pretty bright. The brightest part is the place of my V 37.” Obviously, Herschel now has seen more of the extended emission nebula (Figure 2-131). The object is among his 52 ‘diffused milky

nebulosities', listed as regions 44 and 46 (see section 4.2.1).

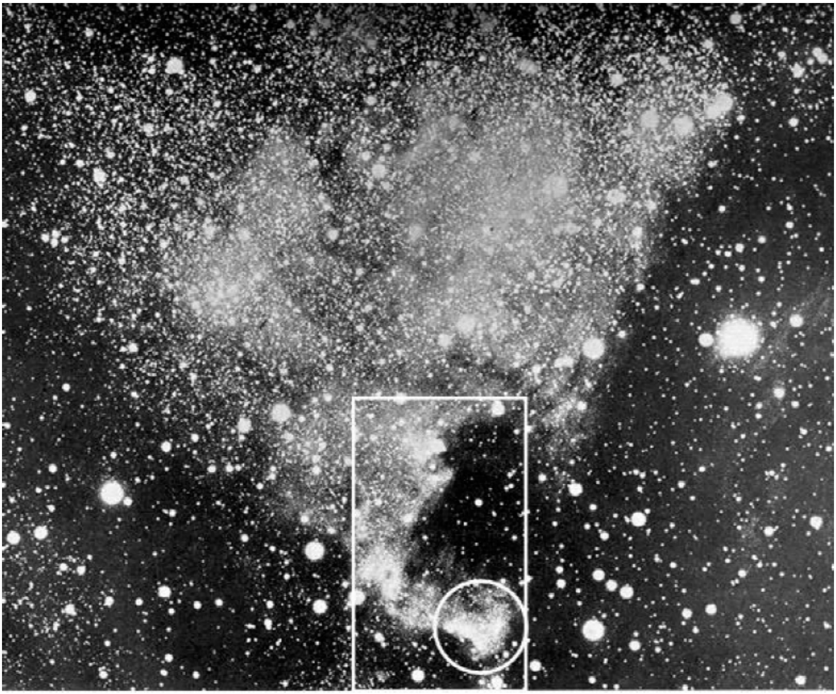


Figure 2-131: The North America Nebula, photographed by Max Wolf. The circle marks Herschel's field of view (showing 'Yucatan'); the rectangular area refers to regions 44 and 46 of his list of 52 'diffused milky nebulosities'.

The sweep brought another remarkable object, the galaxy NGC 7231 (II 606) in Lacerta. It is located in Hubble's 'zone of avoidance' (absorption lane) of the Milky Way, only 9° off the galactic equator. The region looked "extremely rich, in stars of all sizes". The night brought a second sweep (621). Now the stunning edge-on galaxy NGC 891 (V 19) in Andromeda was seen much better than before in the eastern sweep 283 (6 October 1684): "a black division in the middle in the direction of the length". This actually is the 'zone of avoidance' of this spiral galaxy. NGC 891 was sketched (Figure 2-132).

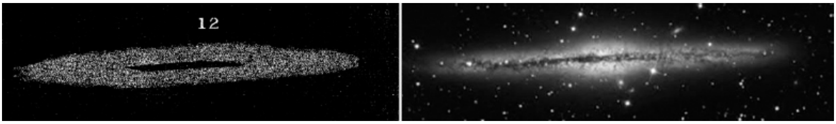


Figure 2-132: The edge-on galaxy NGC 891 in Andromeda (sketched on 24 October 1786) shows a striking dark lane, due to absorption of interstellar matter. The system is similar to the Milky Way.

In the next night (25 October), some bright objects in Andromeda were shown to Charles Blagden: the planetary nebula NGC 7662, M 31, M 32 and NGC 205 ("my sisters nebula"). At about 9 pm, safely placed on the new gallery, he was the first visitor to experience the front-view. One hour after midnight, when the friend had left, Herschel began sweep 623 in Aries. Half an hour later, the task was interrupted by Jupiter, crossing the field of view. Blinded by the light (-2.9 mag), he must recover for 20 minutes ("began again after an interrupt by Jupiter"); shortly after, the sweep was terminated.

On the 26th, "Dr. Hebberdon and the Revd. Mr. Wollaston" enjoyed the fine planetary nebula in Andromeda.[661] Later, the night brought a bright nebula in Triangulum (sweep 626). This is the 10.9 mag galaxy NGC 672 (I 157); the 11.5 mag companion (IC 1727), lying only 8' southeast and bright enough for Herschel's telescope, was missed.[662] Obviously, the galaxy was not on the sweep path und just outside the field of view. The following sweep (628) started with a galaxy pair in Gemini: NGC 2274/75 (II 614/15); the distance is 1.8'. When Herschel left off, he was upset: "Lost a Nebula by the blunder of the man at the motion. It must be looked for another time." This probably was the same person, causing the trouble on 17 April, shortly after the move to Slough, where he had to recruit new personal.[663] The time and PD were not well taken; the only candidate in this area of Gemini (west of Castor) is the 14.5 mag galaxy IC 475, which might be too faint.

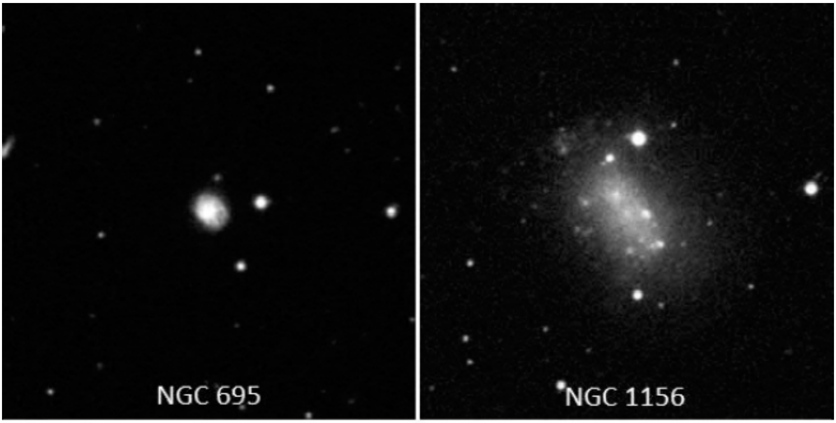


Figure 2-133: Two interesting objects, found on 13 November 1786 in Aries. Left: the ‘stellar’ 12.8 mag galaxy NGC 695. Right: the irregular 11.7 mag galaxy, showing several HII-regions. Both images 5' × 5'.

On 13 November (sweep 636), a ‘stellar nebula’ was found in Aries. The 12.8 mag galaxy NGC 695 (II 618) measures only 40". It is surprising that Herschel perceived such small diffuse objects, when passing the field. In the next sweep (637), he encountered a strange nebula in Aries (“pretty much elongated in the direction of the meridian; a minute of a star”). This is the irregular dwarf galaxy NGC 1156 (II 619), showing a loose structure with some condensations (HII-regions). An unrelated 12th mag star is 1' north.[664] Both objects are shown in Figure 2-133.

In sweep 638 (26 November), Herschel found the galaxy pair NGC 1609/11 (III 585/86) in Eridanus, though not in a single field. It is in a 35' long chain of six 13th mag galaxies, extending from southwest to northeast. That he saw only two members is not due to the “very hazy, or rather cloudy” sky, but to the sweep path, leaving gaps.

On 28 November, Herschel was thrilled by a premiere: “The Nebula in Orion which I saw by the Front view was so glaring and beautiful, that I could not think of taking any place of its extent.” A bit north he saw 42 Ori plus some surrounding stars “involved in nebulosity”; this nebula, NGC 1977, was already found in sweep 510 (18 January 1786) and catalogued as V 30.

In sweep 640 (28 November), Herschel saw "A star involved in milky chevelure, situated between two stars, with a 3rd star at rectangles [perpendicular] to the former two." The nebula in Monoceros was catalogued as IV 44. Dreyer lists it as NGC 2167, but using a wrong position; only a 6.6 mag star is at his place. Herschel's correct coordinates point to an object 16' west: a 9.2 mag star surrounded by a reflection nebula (see Figure 2-67).[665] An unidentified Messier object was observed in sweep 641 on the 28th: the open cluster M 48 in Hydra, found by Caroline on 8 March 1783. Seen twice by William, it now appeared anonymously in the front-view.

On 11 December (sweep 645), William for the first time used reference stars with a PD less than 45°, the limit of Caroline's first zone catalogue of Flamsteed stars. Already in July 1785, she had compiled an expanded version, starting at the pole (PD 0°). Meanwhile, the telescope could reach elevations greater than 83° (PD $<$ 45°) by the modified bar mechanism. The first star, taken from the new table, was 53 Per. In that night, Herschel found an object, which was not catalogued: the 12.1 mag galaxy IC 257 in Perseus, described as: "A few very small stars mixed with very faint seeming nebulosity, in the direction of the meridian; most probably only a patch."

In sweep 650 (15 December), a close pair in Eridanus was discovered: "Two, that of which the place is taken faint, pretty large, the other about 1' nf, exceedingly faint, stellar. A 3rd suspected sf the 1st sill fainter than the 2nd; but I did not see it well enough to verify it, and may be a deception." The pair consists of the 12.2 mag galaxy NGC 1241 (II 286) and its 13.7 mag companion NGC 1242 (III 591), 1.7' northeast. Though there is no third nebula, the pair is interesting. The brighter component (NGC 1241) was already found on 10 January 1785 (sweep 355): "Round, faint, pretty large, large brighter middle, south of a small star." The star, not mentioned later, has 9.2 mag. Why was the faint companion (NGC 1242) not seen by Herschel, although the sky conditions were similar? The first observation was made with the Newtonian focus, the second with the front-view. This demonstrates the advantage of the new optical design. There are two similar cases, shown in Table 2-43 and Figure 2-134.

NGC	H	Sw	Date	V	Size (')	Mode	Con	Dist (')
1241	II 286	355	10 Jan. 1785	12.0	3.4 × 1.6	N	Eri	1.6
1242	III 591	650	15 Dec. 1786	13.7	1.2 × 0.6	FV		
5869	II 545	532	24. Feb. 1786	11.9	2.3 × 1.6	N	Vir	3.6
5865	II 684	727	11 Nov. 1787	13.4	1.1 × 1.0	FV		
1332	I 60	331	9 Dec. 1784	10.3	4.5 × 1.4	N	Eri	3.1
1331	III 959	1091	19 Dec. 1799	13.4	0.9 × 0.7	FV		

Table 2-43: Cases where a fainter companion of an object was seen by the front-view but not in the Newtonian mode.

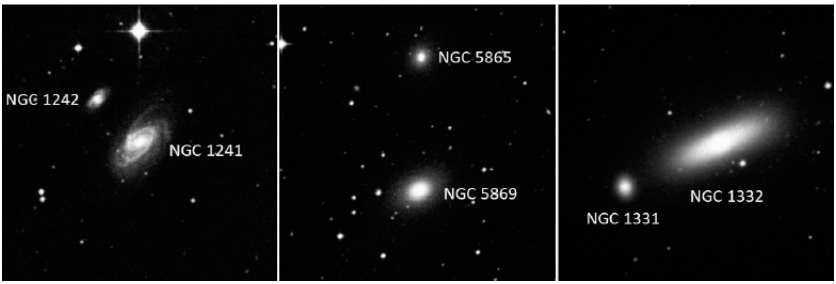


Figure 2-134: The pairs of Table 2-43. The star north of NGC 1242 has 9.3 mag. Note the reversed AR order in the case of NGC 1331/32 (see section 3.2.2). All images 7.5' × 7.5'.

A galaxy trio was found on the 20 December (sweep 655): NGC 426/29/30 in Cetus, catalogued as III 592, II 622 and III 593. The members of 12.9, 13.4 and 12.5 mag, respectively, are within 8'. In the same night (sweep 656), Rigel was seen with its optical companion (“the small star very beautiful”); see Figure 1-12.

Two neighbouring objects were found in Pisces on 21 December in sweep 657. Shortly after Herschel came from inside, where he was exposed to the light, the first was seen: “Very faint, small, 3 or 4 stars in it, but I have not been out long enough; however, I have no doubt.” Right after, in a different field, he had doubts: “Very faint, very small, but I have not long been out enough, and may be a deception.” The first object was listed as III 595; it is the 12.4 mag galaxy NGC 193. The second remained uncatalogued, but it also exists: the 12.9 mag galaxy NGC 204, located 6.7' southeast. We learn: already with a not fully adapted eye, Herschel was able to see such faint nebulae! In the same night (sweep 660), he discovered

two ‘much elongated nebulae’ in Crater at -22° declination. It is the only pair, where both partners are class V objects. However, their sizes do not match the qualification ‘large nebulae’ (see Table 5-15). Actually, these are the galaxies NGC 3511 (V 39) and NGC 3513 (V 40), 10.8' apart (Figure 2-135); they were found one after the other, though in different fields.

Figure 2-135: NGC 3511/13 in Crater with 11.0 and 11.5 mag; it is the only pair of class V objects (‘large nebulae’).

In sweep 666 (26 December) Herschel saw in Orion “some very small closely scattered stars; not enough of them to be called a cluster”. Later that night (sweep 667), he found “A cluster of much compressed small stars, considerably rich.” He believed to have seen only “a condensed part of the Milky Way” in Monoceros: “Not to be put in the clusters.” The object was not catalogued. In the first case (Orion), Herschel was right to see only a loose ensemble of 14th mag stars, just filling the field of view. But not so in the second (Monoceros): the object is the open cluster Cr 115.[666] The brightest stars are of the 10th magnitude. Both objects are shown in Figure 2-136.

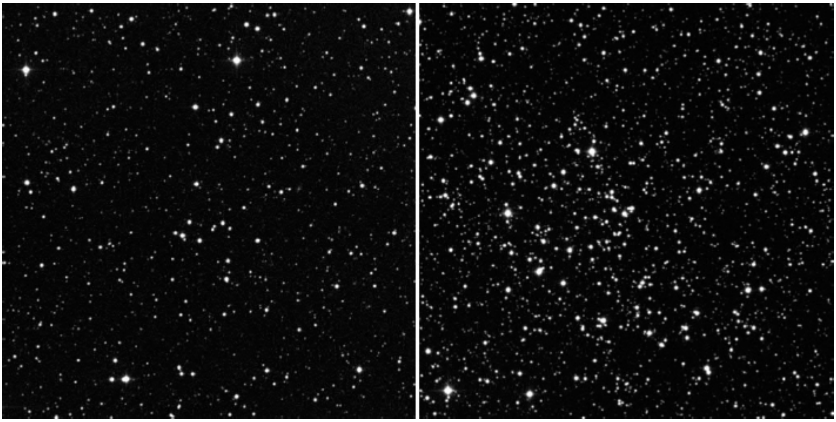


Figure 2-136: Doubtful objects, found on 26 December 1786: a coarse star group in Orion (left) and the open cluster Cr 115 in Monoceros (both images 15' × 15').

The open cluster, found on 27 December (sweep 668), left no doubts: "A very beautiful cluster of much compressed large and small stars, of many sizes above 20' diameter." This is NGC 2301 (VI 27) in Monoceros. The night had actually more to offer. In sweep 671, Herschel saw an "eF, eF" object: "suspected, but may be a deception". It was not catalogued, but the position clearly points to the 13.1 mag galaxy NGC 3910 in Leo. Only three minutes later a similar case occurred: "Suspected; but doubtful; probably 2 very faint and very close stars." The object was again not catalogued. It was not realized that this is the small 12.8 mag galaxy NGC 3940 (III 380) in Leo, found on 26 April 1785 (sweep 402). About 10 minutes later, Herschel met a known ensemble in Coma Berenices, the famous galaxy sextet, discovered on 27 April 1785 in sweep 403 (NGC 4061/65/66/70/74/76); see Figure 2-93. The three additional, uncatalogued galaxies (NGC 4060/69/72) are not mentioned.

In sweep 673 on 29 December, Herschel searched in vain for his nebula III 112 in Leo, the 13.6 mag galaxy NGC 3679, discovered on 24 April 1784 (sweep 205). He wrote: "Looked for the Nebula III. 112 and though the night is apparently not a bad one, I could not find it. I examined a great part of the heavens in the neighbourhood but saw nothing of it. Nebula that can disappear in so short a time cannot be clusters of stars at a distance." To find out

the reason of his failure, one must look into an earlier version of the sweep 205 record (*Journal No. 8, Fixt Stars No. 7*). Here we find the reference star used at that time: φ Leo. In the later written document *Sweeps No. 1*, a different star is mentioned: ‘Mayer’s 510 Zodiacal’.[667] In the former record we read: “considerably large, excessively faint, round, resolvable, just preceding, and very near a bright star. The nebulosity touches the star. There is so much moon light that I do not see is satisfactorily, and am, even not without some doubts as to the reality, but must defer the verification till a darker night […] But φ being the first star the determination is probably affected with considerable inaccuracy.” φ Leo was the first object of the sweep, affected by moonlight and “flying clouds”; it was taken as reference star. In the early sweeps the determination of relative positions was still problematic. Of course, Herschel has seen the galaxy; the mentioned “bright star” has 7.8 mag and is 2.8' north. Taking the former record, the nebula should be 10.1^m east and 1° 52' south of φ Leo. The resulting place is 1.2° northwest of the galaxy. This was the information, Caroline offered her brother in sweep 673. Obviously, William searched at the wrong position. In the sweeping mode, the 20-ft was not able to look around, like the smaller reflectors. Caroline’s later reduction (with Mayer’s zodiacal star) also gives a wrong position, 1° west of the galaxy.

The busy year 1786 ended with sweep 675 on 30 December. Three galaxies were seen in Leo. The first is NGC 3401 (III 88), already found in sweep 191 on 13 April 1784. The second was new: NGC 3509 (II 598). Then Herschel saw NGC 3604 (II 626). He did not realize that this is II 521, already found on 27 January 1786 (sweep 514). Dreyer did not notice the identity either and catalogued the latter as NGC 3611. In sweep 675, Caroline made an AR error of 1^m, thus she could not identify both entries.

2.5.5. Summary of 1786

Table 2-44 gives the statistical data of the sweeps made in 1786, starting with no. 504 on 1 January and ending with no. 675 on 30 December. There are three records: the longest observing night (12.8 hours), the number of uncatalogued objects (13) and the number of re-observed objects (305).

Category	Value	Remarks
number of nights	94	
longest continuous period (days)	7	17 – 23 September
longest break (days)	52	28 June – 19 August (William in Hanover)
number of sweeps	174	
sweeps per night (maximum)	10	27 Jan.
mean night (hours)	3.5	
longest night (hours)	12.8	1 January (observing time 10 hours); *record*
lowest elevation (°)	10	28 Mar.
highest elevation (°)	86	PD 43°, several sweeps
lowest PD (°)	23	
observed objects	626	
objects per night (mean)	6.5	
sweeps without objects	44	
new objects (all)	321	
uncatalogued objects	13	Table 5-5; *record*
re-observed objects	305	*record*
most productive night	24 Feb.	50 objects
new objects: first	1 Jan.	NGC 1032 (Gx Cet)
last	30 Dec.	NGC 3604 (Gx Leo)
brightest (mag)	5.8	M 48 (OC Hya)
faintest (mag)	14.6	NGC 1516 (Gx Eri)
smallest (")	20	NGC 6543 (PN Dra)
multiple	13	11 pairs
Messier objects:	48	
first observation	2	
first with 20-ft	8	
new stars: double	11	
new garnet stars	3	
star gages	33	
vacant places	36	

Table 2-44: Sweep statistics for 1786.

The year saw the siblings move from Clay Hall (Old Windsor) to their final destination, Slough. Caroline found her first comet, while William and Alexander visited Germany. The 20-ft was rotated to the north to observe 'under the pole'. Later the front-view was installed and used until the end of its existence. The new optical design brought spectacular views on M 42 and the Veil Nebula; the North America Nebula NGC 7000 in Cygnus was discovered. With the 'bar index' high elevations were controlled. In the summer, the work on the 40-ft telescope began. Caroline compiled a new (second) zone catalogue for Flamsteed stars, now including those with PD $< 45°$. The first Herschel catalogue of nebulae and star clusters was eventually published at the end of the year. William watched his first Mercury transit.

2.6. Observations in 1787 – satellites and first light of a giant

2.6.1. Two moons of Uranus

11 January brought another triumph for Herschel. In sweep 683 (the fourth of the night) he encountered Uranus, located in Gemini near the border to Cancer. 25 minutes past midnight, the 5.4 mag bright planet crossed the field of view of the 20-ft at an altitude of 22°: "The planet is in a row nearly with 2 following stars, which differ not much in magnitude. […] There is a 1st supposed satellite about ½ min south following the Planet and a 2nd about 1' north preceding the Planet. […] A third supposed satellite (but not very likely) is south following the planet." A sketch was made (Figure 2-137).[668] The first moon is Titania (13.6 mag), 33" south of Uranus, the second Oberon (13.8 mag), 45" north.[669] Herschel credited the important discovery to the front-view mode, permanently used since 13 October 1786 (sweep 609).

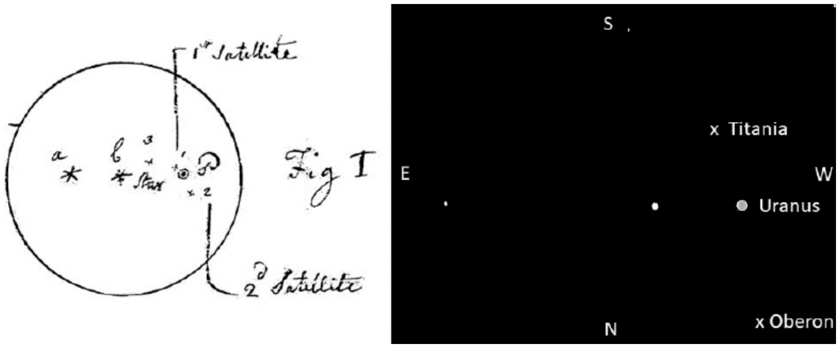


Figure 2-137: Herschel's discovery of Titania and Oberon, the brightest moons of Uranus, on 11 January 1787. Due to the front-view, the sketch is upside down (and a bit rotated); the right figure shows the exact situation at 0:20 am. He assumed that the star at the top is a third moon, but this was not confirmed later.

This observation of Uranus led to a revival of the *Journal* series; *Journal No. 10A* had been closed on 21 December 1784 after sweep 350. Now, about two years later, Caroline opened *Journal No. 10B*; the first entry concerns the discovery of the two satellites.

On 11 February, Herschel sent a paper to the *Royal Society*, titled 'An Account of the Discovery of Two Satellites revolving round the Georgian Planet'.[670] There we read about the discovery:

[…] while it passed the meridian, I perceived near its disk, and within a few of its diameters, some very faint stars whose places I noted down with great care. The next day, when the planet returned to the meridian, I looked with a most scrutinizing eye for my small stars, and perceived that two of them were missing. Had I been less acquainted with optical deceptions, I should immediately have announced the existence of one or more satellites to our new planet; but it was necessary that I should have no doubts. The least haziness, otherwise imperceptible, may often obscure small stars; and I judged, therefore, that nothing less than a series of observations ought to satisfy me, in a case of this importance. To this end I noticed all the small stars that were near the planet the 14th, 17th 18th, and 24th of January, and the 4th and 5th of February; and though, at the end of this time, I had no longer any doubt of the existence of at least one satellite, I thought it right to

defer this communication till I could have an opportunity of seeing it actually in motion. Accordingly I began to pursue this satellite on Feb. the 7th, about six o'clock in the evening, and kept it in view till three in the morning on Feb. the 8th; at which time, on account of the situation of my house, which intercepts a view of part of the ecliptic, I was obliged to give over the chace: and during those nine hours I saw this satellite faithfully attend its primary planet, and at the same time keep on, in its own course, by describing a considerable arch of its proper orbit.

On 8 March 1790 at 9:30 pm, Herschel viewed Uranus for the first time with the 40-ft. It was 5.4 mag bright and was 1.6° southeast of M 44, 58° above the horizon in the meridian. However, the image was not really pleasant: “I saw the satellites with great ease; the Speculum is extremely tarnished and I did not expect to have seen half so well as I did.” This would be the only observation of the planet with the large reflector.

Uranus and his moons were occasionally shown to visitors, like Charles Blagden on 19 February. It is interesting that it would take until 1847 for a study with a comparable telescope. In that year, William Lassell, owner of the ‘Starfield Observatory’ in Liverpool, turned his equatorial 24-inch reflector to the planet.[671] He measured the position of Herschel’s satellites. Eventually, he discovered two more on 24 October 1851, Ariel and Umbriel. Lassell requested John Herschel to name the four moons, which he did in 1852.[672]

Recently, it has been claimed that Herschel had detected the rings of Uranus.[673] This is based on observations, made 1787, 1789 and 1792 with the 20-ft reflector; four sketches were made (Figure 2-138).[674]

Figure 2-138: Herschel’s sketches of Uranus. Do they in fact show rings?

On 4 March 1787, the planet appeared “not round [...] perhaps a double ring; that is, two rings, at rectangles to each other”. On the 7th, Herschel measured their diameters (R, r), but writing on the 8th that “R and r are probably deceptions”. For 9 November, we read: “The suspicion of a ring returns often when I adjust the focus by one of the satellites, but yet I think it has no foundation.” On 22 February 1789 “a ring was suspected” and on 16 March, he noted: “I have turned my speculum 90° round. A certain appearance, owing to a defect which it has contracted by exposure to the air since it was made, is gone with it; (see fig. 9 and 10) but the suspected ring remains in the place where I saw it last.” He added: “The ring is short, not like that of Saturn. It seems to be as in figure 8; and this may account for the great difficulty of verifying it. It is remarkable that the two ansæ seem of a colour a little inclined to red. The blur occasioned by the fault of the speculum is, to-night, as represented in figure 9. The other evening it was as in figure 10; and the ring is likewise as it was the same evening.” Further observations were made in 1792. On 26 February, Herschel wrote:

My telescope is extremely distinct; and, when I adjust it upon a very minute double star, which is not far from the planet, I see a very faint ray, like a ring crossing the planet, over the centre. This appearance is of an equal length on both sides, so that I strongly suspect it to be a ring. There is, however, a possibility of its being an imperfection in the speculum, owing to some slight scratch: I shall take its position, and afterwards turn the speculum on its axis.

On 5 March, Herschel finally wrote: “I viewed the Georgian planet with a newly polished speculum, of an excellent figure. It shewed the planet very well defined, and without any suspicion of a ring.” Had he actually seen Uranian rings? Due to their low albedo, they appear very dark. Thus, it is impossible that he was able to perceive them.[675] However, Uranus is not perfectly round, showing a significant flattening: the equatorial diameter is 51,118 km, while the polar diameter is only 49,946 km. The discovery of this property is actually attributed to Herschel; on 8 April 1783 he wrote: “I surmise a polar flattening”.

2.6.2. Enceladus and first light for the 40-feet reflector

Sweep 683 of 11 January was not the first one in 1787. The new year started with no. 680, using “a polished large speculum, the figure is very good” – perhaps another reason for the discovery of the Uranian moons (beside the front-view). The first object was the ‘large nebula’ V 17 in Triangulum. Already known from sweeps 266 and 268 in September 1784, the object was now seen in the front-view mode. Once again, William was not aware to observe M 33! Curiously, Caroline added a ‘memorandum’: “Looked for the 33rd of the Conoiss. des temps, but it is not in his place.” He also saw the associated “small nebula” III 150 (NGC 604). 25 minutes later, it is noted: “A patch of a few small stars. The place not very accurate.” However, it is good enough to identify the ‘patch’ with the 12.9 mag galaxy NGC 769; another pretty bright, uncatalogued object. The next would follow soon.

The night of 14 January was the most productive of the whole year; three sweeps were made. Herschel observed 41 non-stellar objects, 11 were new. Among them is an uncatalogued one, found in Leo (sweep 691): “very faint, very small, most likely a small patch”. This is the 12.5 mag galaxy NGC 3419. The sweep also brought another observation of the galaxy M 91 in Coma Berenices. Again, due to Messier’s wrong position, Herschel was not aware of its identity. He independently had found the nebula on 8 April 1784 (sweep 187), catalogued as II 120. Curiously, it appears twice in sweep 691. 72 seconds after the first observation, he noted: “The same nebula taken again, as I was not quite sure whether it might not be another, but former time and place is more accurate; this being already out of the field.”[676] This was possible because the first measurement was made in the eastern half of the field (AR offset $+24^s$). When the nebula had reached the western edge (offset -40^s), the position was taken again. The AR offsets are described in Figure 2-139.

In the same sweep, M 98 and M 99 were seen, correctly identified. Three days later (sweep 603), the open cluster M 38 in Auriga was observed for the first time with the 18.7-inch (“extremely rich and

beautiful”).

On 17 January (sweep 693), Herschel changed his mode of measuring a reference star: “The position will in future be always taken from the parallel.” Consider the following situation (Figure 2-139): The telescope is in ‘sweeping motion’ (up/down) and a star or non-stellar object comes into view, entering the field at the upper/lower edge. William now gives the command to the workman at the handle to hold it. Assume that the entrance is in the meridian (central vertical line). In the ideal case, the tube comes to rest, when the object is in the centre of the field of view (0). Caroline now notes the sidereal time (ST) and the PD. If both the sidereal and PD clock work exactly, the ST is equal to AR and the PD gives the correct declination. We now have a reliable absolute position. The object moves further to the western end of the field by the sky motion on the ‘parallel’ (horizontal line of constant PD). Now there is time for William to shout the description to Caroline; an object at the equator needs one minute to cross the field, more at higher declinations (see Figure 2-167).[677]

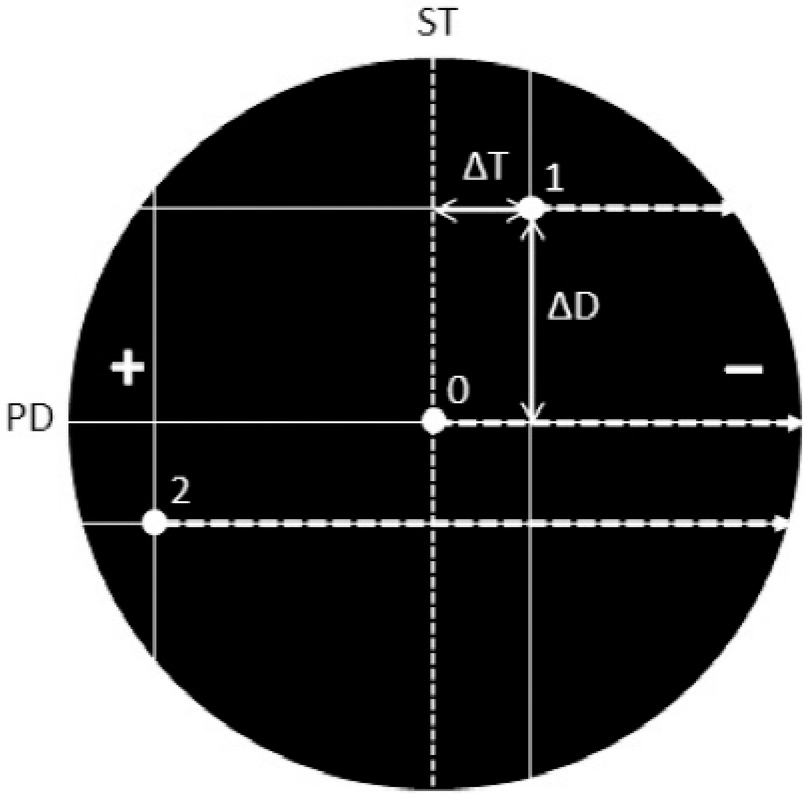


Figure 2-139: Objects, motions and distances in the field of view. The vertical dashed line is the south meridian. The signs + and – denote the AR offset, written down in the sweep record, when an object was measured east or west of the meridian. The horizontal line going through the centre (0) is called 'parallel' (see text).

In practise, the ideal (central) position is not realized; there are differences (ΔT, ΔD). Let's first assume that $\Delta D = 0$. The object is then on the 'parallel', i.e. the horizontal line going through the centre (0). The difference ΔT (in seconds) was noted and taken into account for the AR determination; a positive (+) or negative (-) offset means that the object was measured east or west of the meridian (i.e. in the following or preceding part of the field). The maximum value for ΔT corresponds to half of the field diameter (the amount in second of time depends on declination). If the object is east of the meridian, Herschel waited until it has reached it to take the ST. The advantage: more time for description. Of course,

this time is shorter if the object appears west of the meridian. In such a case, a remarkable object was followed by the ‘side motion’ to the west (up to several fields of view).

The PD position is more essential ($\Delta D \neq 0$): above or below the ‘parallel’, the horizontal path of the object is shorter (zero at the upper/lower limit). Thus, it was always tried to stop the sweep motion at or near the ‘parallel’. The difference ΔD (in arcminutes) was noted and taken into account in the PD determination. In most cases the values did not exceed $\pm 1'$. The important objects are reference stars; they should be determined with the highest precision, i.e. on the ‘parallel’ (this is Herschel’s statement). Critical reference stars are those, seen west of the meridian (in the east one had only to wait for the meridian passage to take the time).[678] Generally, the new directive led to more precise relative positions for non-stellar objects.

On 17 January (sweep 694), Herschel discovered a striking object, much looking like his famous ‘star with an atmosphere’, IV 69 (NGC 1514) in Taurus, to be discovered on 13 November 1790. He wrote: “A star with a pretty strong milky nebulosity equally dispersed all around. The star about 9 m. Having that just began I suspected the glass to be covered with damp, or my eye not yet to be in order; however a star 10 or 11 m, just north of it was free from the same appearance. A very curious phenomena; like my northern planetary in its growing state.” This is the 9.1 mag planetary nebula NGC 2392 (IV 45) in Gemini, known as the Eskimo Nebula; the conspicuous central star of 10.5 mag shines through the nebulous shell (Figure 2-140).[679] Herschel roughly determined the position of the nebula by the open cluster VI 1 (NGC 2420), seen nine minutes later. A better one resulted in the next night (sweep 695), when the bright star δ Gem was used. He was again impressed by the curious object: “One of the most remarkable phenomena I ever have seen.” It was compared, in an evolutionary sense, with NGC 7662 (IV 18) in Andromeda, though there is no visible central star. Herschel saw NGC 2392 a third time, on 26 February 1794, now with the 6.2-inch reflector: “My nebulous star appears like a dull star with extensive very faint nebulosity about it.”

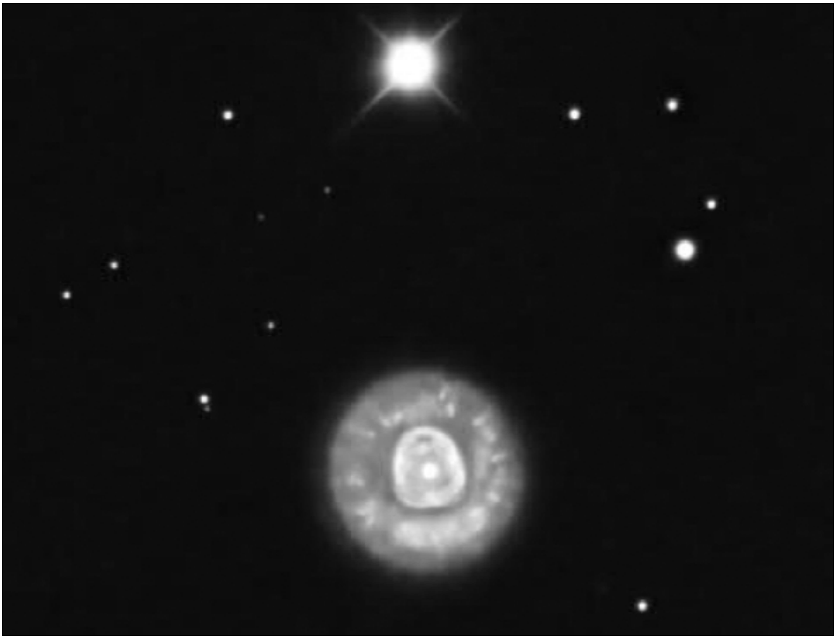


Figure 2-140: ‘A very curious phenomena’: the planetary nebula NGC 2392 in Gemini, found on 17 January 1787 and known as the Eskimo Nebula. The 10.5 mag central star was clearly seen. The 8.3 mag star, being ‘just north of it’, is at the top (distance 1.7').

The discovery of two moons of the ‘Georgian Planet’ inspired Herschel to watch them alongside the sweeps. This first happened on 13 February. Prior to that date, planets were viewed in the meridian with the 20-ft while sweeping. Now Uranus was frequently viewed before or after a sweep with different telescopes. Most of these observations are not noted in the sweep records, but recorded in *Journal 10B*, *11* & *12*, reserved for planets, variable or double stars (occasionally Messier objects are also mentioned).[680] In the night of 13/14 February, two sweeps (698, 699) were made: the first started at 9:49 pm and ended at 11:08 pm, the second started at 1:55 am (on the 14th) and ended at 3:56 pm. There is no word about Uranus, but *Journal 10B* notes four observations, ordered by sidereal time. The first is at ST 5^h 2' (7:30 pm); the second followed at 5^h 19' (7:47 pm). At that time the planet was in western Gemini, 60° west of the meridian at 50° altitude. The third observation was at 7^h 34' (10:05 pm), with Uranus now in the

meridian (altitude 61°). The last was at 9^h 39' (0:07 am), 50° west of the meridian at 52° altitude.[681] Obviously, the third observation lies in sweep 698, though not mentioned in the record. Actually, the planet was on the path and has been seen in the field of view (four minutes after the reference star 79 Gem had passed). What about the other observations? The first two were made before sweeping and the last between sweep 698 and 699, in the 2¾ hour break. Because Uranus was not in the meridian, the 20-ft had to be turned in azimuth by the 'round motion'. For this, the 'PD string' had to be removed (obviously, this was done rather quickly).

Such mixed observations became normal. 19 August started with sweep 752 at ST 19^h 49^s (10:06 pm); the observation ended already at ST 20^h 38^s (10:47 pm). Only a double star (N55) was found in Vulpecula. Shortly after midnight, the 20-ft was turned to Saturn, located in Capricornus. The planet was observed at 21^h 26^s (0:35 am on the 20th). The night before, Herschel thought to have seen a new moon, called the 'fifth', but now he noticed that "The 5th of the last night remains and the real 5th is now near the star marked as b last night and the star a of last night is wanting." This marks the discovery of Enceladus, shining at 11.8 mag! Of course, Herschel's satellite counting is wrong: Enceladus actually is the sixth moon. In the literature we find that he discovered it on 28 August 1789 with the 40-ft. The sixth moon was actually seen in the large telescope at this point, if not for the first time! The error may be due to Herschel himself, not remembering his former observation with the 20-ft on 20 August 1787. In a postscript to Herschel's second catalogue of nebula and star clusters of 1789, we read:[682]

The planet Saturn has a *fifth satellite* revolving round it in about 32 hours, 48 minutes. Its orbit lies exactly in the plane of the Ring, and within that of the first satellite. An account of its discovery with the forty-feet reflector, and a more accurate determination of its revolution and distance from the planet will be presented to the Royal Society at their next Meetings.

Again, he speaks about a 'fifth satellite'. Herschel soon noticed his error, writing to Joseph Banks on 4 September 1789: "Saturn has six satellites. An account of its discovery, its revolution and orbit will be given in the next vol. of the Ph. Tr. [*Philosophical*

Transactions].” Curiously, Mimas, the seventh moon, was also falsely reported to have been found with the 40-ft (on 17 September 1789). Herschel saw it already on the 8th with the 20-ft! In autumn 1789, the ring of Saturn was nearly edge-on, offering a good chance to find new satellites.[683]

Another mixed observation was made in the night of 10/11 October 1787. Before sweeping (“in the early part of the night”), still on the 10th, Herschel checked Rigel for its companion with the 7-ft. Blinded by the light, he was not successful. Shortly before midnight, he started sweep 764, lasting from ST 0^h 27^s to 3^h 31^s (11:19 pm to 2:23 am). It was made in the north, above the pole. At an elevation of about 72° (PD 20°) objects in Cassiopeia and Camelopardalis were viewed. In *Journal No. 11* five observations of Uranus are recorded, made between ST 5^h 32^s and 6^h 03^s (4:24 pm to 4:55 pm). At that time the planet was about 50° east of the meridian at 50° altitude – pretty far from the north. In the two-hour period between the end of sweeping and the Uranus observation, the telescope was turned 130° by the ‘round motion’. The planet is not mentioned in the sweep record.

An unusual experiment is reported at about 1:50 am. By the front-view, Herschel looked with his right eye into the eye-piece, installed at the left side of the tube opening. While his head was directed to the south, he was “Looking at Sirius with the naked eye while I look in the telescope with the other; I find that the stars of the 9th magnitude or 9 to 8 are about equal to it in brightness.” Sirius was 50° to the east, 8° above the horizon. In 1787, Herschel combined sweeping with other observations in 10 nights.

The 40-ft reflector, designed as a front-view, saw a (provisionally) first light on 19 February 1787. In the garden at Slough, it stood south of the 20-ft, about 40 feet southwest of the main house (Figure 2-141).[684] The mirror was installed in the tube at that day, but the mounting was still under construction. Nevertheless, Herschel was eager for a first test – the target was, of course, the Orion Nebula. At 7:30 pm, M 42 crossed the meridian at an altitude of 32°. The tube was raised and the nebula appeared in the eye-piece, held by hand for an improvised front-view:[685]

The apparatus for the 40 feet telescope was by this time so far

completed that I could put the mirror into the tube, and direct it to a celestial object; but having no eye glass fixed, nor being acquainted with the focal length which was to be tried, I went into the tube, and laying down near the mouth of it I held the eye glass in my hand and soon found the place of the focus. The object I viewed was the Nebula in the belt of Orion, and I found the figure of the mirror though far from perfect, better than I had expected. It showed the four small stars in the Nebula [Trapezium], and many more. The Nebula was extremely bright.

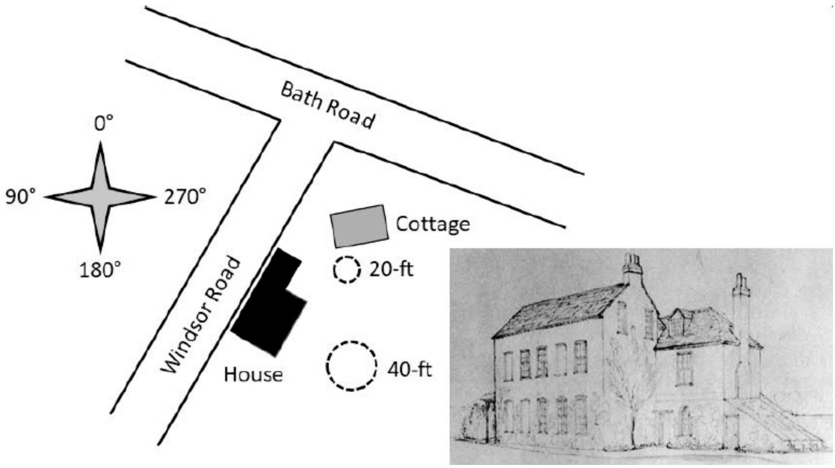


Figure 2-141: The 'Slough observatory'. The view of the 20-ft reflector was limited to the southwest by the main house (inset). However, for an azimuth $< 140°$, objects with altitude $> 50°$ were visible above the roof (compare Figure 2-119 and Figure 2-123). The 40-ft had a clearer view, but there is no report for observations off the south meridian (the possible 'round motion' remained unused).

Herschel had a welcome guest, Charles Blagden, who came to see Uranus and his moons with the 20-ft. However, there was another target, the galaxy M 64 in Coma Berenices (Figure 2-142), which led to a surprising result: "Dr. Blagden saw the 64th of the Connoissance des temps with a black arch under the bright point." In 1833 John Herschel wrote about this observation: "It was however seen by my Father, and shown to the late Sir Charles Blagden, who likened it to the appearance of a 'black eye', an odd,

but not inapt comparison."[686]

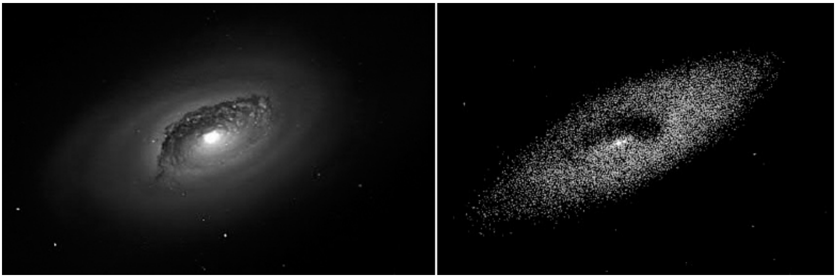


Figure 2-142: M 64 in Coma Berenices with its remarkable dark structure; the name Black Eye Galaxy is due to a remark of Charles Blagden. John sketched the object on 21 April 1833 at Slough.[687]

The discovery of two Uranian moons with the 20-ft by the front-view, convinced Herschel to apply this design to the 40-ft (initially a Newtonian was planned). The optical system was installed in June, together with a slide device to hold several eye-pieces.

The year 1787 brought two more observations with the giant telescope. On 10 July, Herschel saw an anonymous "cluster of stars with nebulosity just south following." On 20 November, Mars (-0.5 mag) and Uranus (5.4 mag) were first viewed. The red planet was only 3.7° northwest of Uranus in Cancer.[688] When the meridian was crossed at about 4 am, the duo was 61° above the horizon:[689] "it had a great deal of light, I could only perceive some very indistinct spots on its disk, the fault of the figure of the Speculum is too considerable to permit any precision. I saw the Georgian Planet and perceived the 1st satellite with much difficulty, its light being still too much scattered by the bad figure".

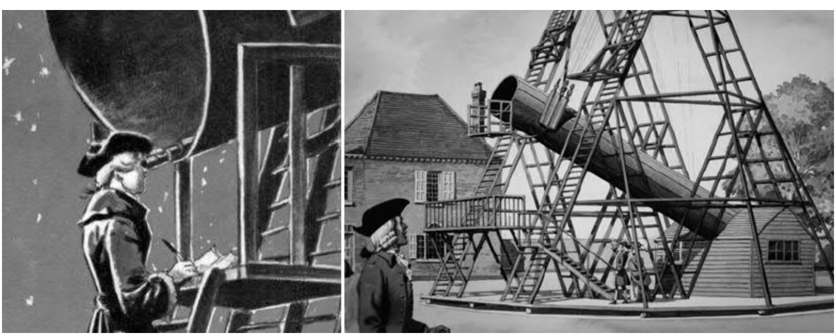


Figure 2-143: Crazy pictures of Herschel and the 40-ft reflector (compare Figure 2-24). Left: He is shown looking into the eye-piece (front-view) and making notes in the night, while the tube points at the ground! Right: Here the telescope is erected in the garden at Datchet, where it never stood!

On 24 October 1788, the now operational 40-ft was tried upon the ringed planet ("I see Saturn very well.").[690] On the 28th a first test sweep was made, another one followed on 23 November (see section 2.7.2). However, Herschel wrote on 28 August 1789: "I may date the finishing of the 40-feet telescope from that time."[691]

2.6.3. Further observations of nebulae and clusters, reaching the zenith

On 22 February (sweep 704), Herschel found a remarkable nebula in Sextans, the Spindle Galaxy NGC 3115: "Extremely bright, much extended from about 45° sp to nf, considerably large. The bright part about 2' long with very faint branches extending in all, to 4 or 5'." The 8.9 mag lenticular galaxy is seen nearly edge-on.

Nothing happened until 7 March (sweep 707). Viewing in Hydra, Herschel saw "3 or 4 unequal stars with faint nebulosity between them, but may be a few much smaller stars mixed with them, and I rather suppose that to be the case." The find was not catalogued. Wrongly, because the place is occupied by the 11.9 mag edge-on galaxy MCG -1-24-1. Surprisingly, the bright object is not in the NGC.[692] Both objects are shown in Figure 2-144.

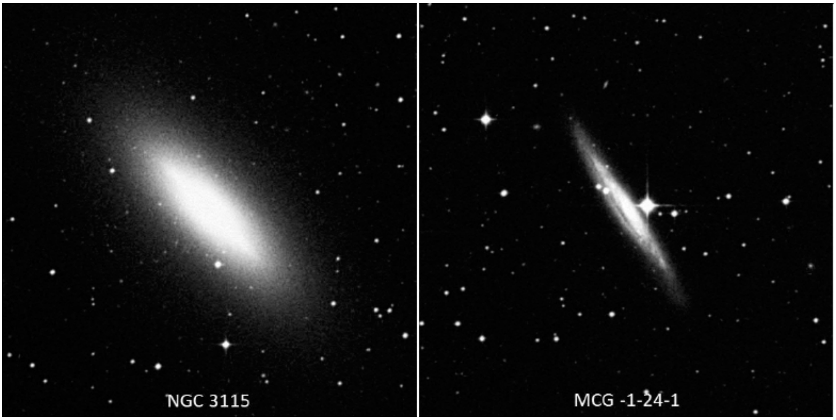


Figure 2-144: Two remarkable edge-on galaxies. Left: NGC 3115 in Sextans, discovered on 22 February 1787. The 8.9 mag object is known as the Spindle Galaxy. Right: The 11.9 mag galaxy MCG -1-24-1, found on 7 Mach 1787, should be in the NGC but it was overlooked by any subsequent visual observer (both images 10' × 10').

In the following nights, three Messier objects were seen for the first time in the 18.7-inch. On 15 March (sweep 711), Herschel viewed the large face-on galaxy M 83 in Hydra.693 The object is described as "A bright round nucleus with faint branches about 5 or 6' long, extended from sp to nf." It is astonishing that he perceived these structures, while the galaxy was only 10° above the horizon. What are the 'faint branches'? The galaxy has two spiral arms, each about 6' long. Due to the face-on view, the structure appears in all its glory. Herschel could have seen the arms, but did not realize the spiral structure. It is more likely that he perceived the 3' long bar, oriented southwest-northeast. Sweep 1041 (5 May 1793) brought the second observation of the bright galaxy M 83 in Hydra after sweep 711 on 15 March 1787. Herschel noted: "Very bright. A small bright nucleus with very extensive and very faint nebulosity, it more than fills the field; it seems to be rather stronger from sp to nf. It may be ranked among the nebulous stars." No 'branches' are mentioned now.

There is a similar case: M 74 in Pisces, where the two arms are not so well defined. Two-armed face-on galaxies are called 'grand design' spiral galaxies (Figure 2-145). The observation of 14

October 1784 (sweep 289) with the 20-ft had brought no clear result. But the object was observed on 28 September 1799 with the 40-ft! Alas, the unique opportunity could not be used, the mirror was steamed up due to moisture: “Very bright in the middle, but the brightness is confined to a small place; and is not round, about the bright middle is a very faint nebulosity to a considerable extent. Not less than 2/3 of the field of view, and probably much farther. The bright part seems to be of the resolvable kind; but my mirror has been injured by condensed vapours.” With 280×, the 9.5' field of view fit well to M 74.[694] Under better conditions, the spiral structure would have been detected by Herschel – 46 years before Lord Rosse’s success with M 51 (see Figure 2-58).

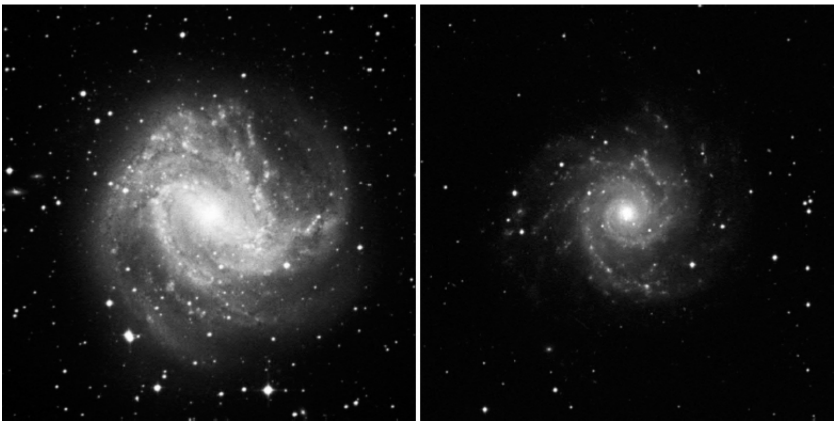


Figure 2-145: ‘Grand design’ spiral galaxies: M 83 in Hydra and M 74 in Pisces. Herschel saw ‘branches’ in M 83 which could be interpreted as ‘spiral arms’.

Two Messier galaxies were viewed on 18 October in Canes Venatici (sweep 717): M 94, treated as an ‘annular nebula’ by John (see Figure 3-19) and M 63, known as Sunflower Galaxy (Figure 2-146).

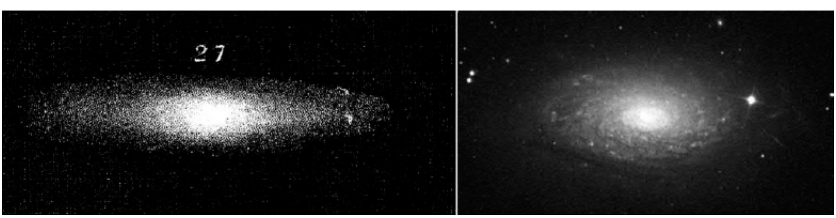


Figure 2-146: The Sunflower Galaxy M 63 (8.6 mag) in Canes Venatici was sketched on 18 October 1784.

Back to 15 March. In sweep 714, Herschel found one on the flattest known galaxies, NGC 4244 (V 41) in Canes Venatici (Figure 2-185). The 10.4 mag object has an axis ratio of 8.7. Herschel wrote about the stunning view: “Considerably or very bright, 18 or 20' long, about 2' broad, from about 60° sp to nf, very gradually brighter middle”.

An interesting puzzle is associated with Herschel’s discovery of the 12.4 mag galaxy NGC 3930 (III 616) in Ursa Major, made on 17 March 1787 in sweep 714. He wrote: “very faint, considerably small, just south of a star 6m. I suspected at first that my glass [eye-piece] had been affected with damp.” The star, seen 3' north, was not identified and listed as U[760]. A second observation was made on 23 March 1789 in sweep 915: “exceedingly faint, irregularly formed, 3 or 4' diameter, about 5' south of a star 6m.” When Caroline revised the sweep records, she could identify the unknown star in Bode’s catalogue of 1801 as ‘333 Ursae Maj. Of Bode’s Cat. L’s obs.’ This refers to the very source: Lalande’s star catalogue *Histoire Céleste* (the star was observed in 1794). In Baily’s revision of 1847, Herschel’s star is listed as LL 22369.[695] The position for 1800 is indeed about 3' north of the nebula.

What is the puzzle? Using a planetarium software (*Guide 9.1*) or the real sky (*Palomar Observatory Sky Survey*), there is no brighter star north of NGC 3930. The author first checked variable stars, with no result. A star cannot ‘disappear’, there is no ‘inverse nova’. Checking the best star database (*Simbad*) for LL 22369, the solution became obvious. The missing star is Groombridge 1830. It found by Stephen Groombridge in the 1810s during his measurements of 4243 circumpolar stars. In 1842, Argelander detected a large proper motion of 11.8' per century.[696] From 1787 to 2021 the Groombridge 1830 has moved 28' to the southeast (Figure 2-147).

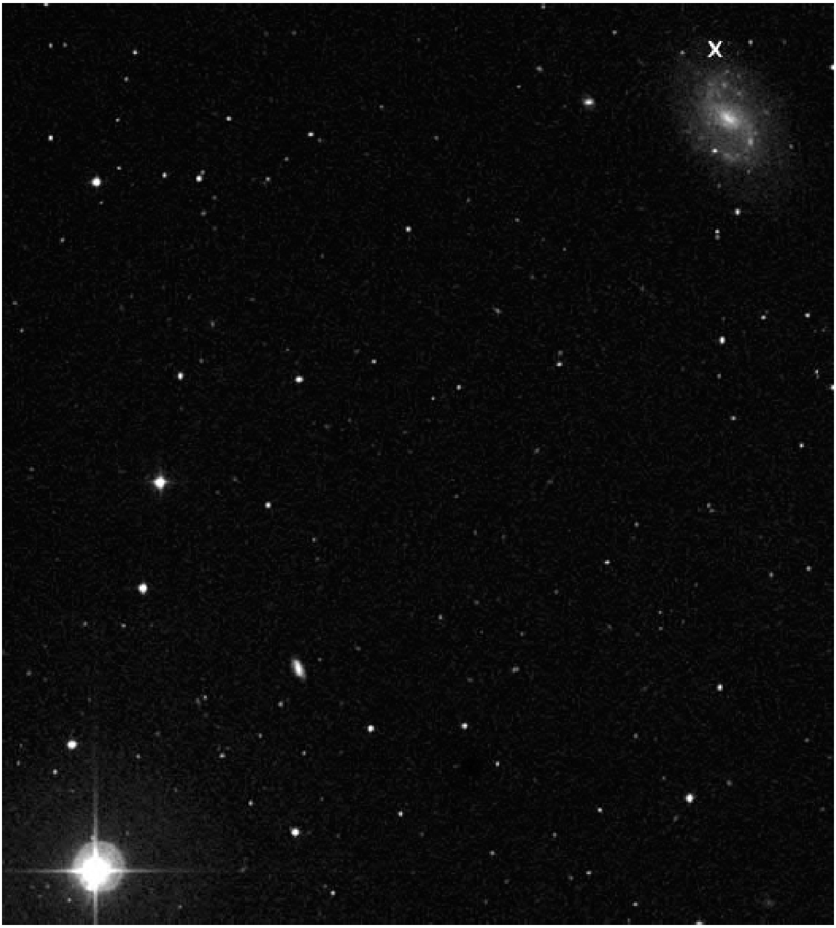


Figure 2-147: The 6.4 mag star Groombridge 1830 was seen by Herschel in 1787 and 1789 just north of the galaxy NGC 3930 in Ursa Major (x), not knowing about its nature. It is the star with the third largest proper motion. When the *Palomar Observatory Sky Survey* image was taken in 1996, it has moved 24' to the southeast (lower left corner).

On 17 March (sweep 715), Herschel found three faint galaxies in Corona Borealis and one in Hercules. The observing session started with the 13.5 mag galaxy NGC 6038 (III 622), writing “I saw it in the field while I was gaging otherwise it would have certainly been overlooked, 300 shewed the same plainly.” This fact led him to sweep with 300× for the rest of the night (the field of view was

only 8').697 The new discoveries were NGC 6120 (III 623, 13.9 mag), NGC 6137 (III 624, 12.4 mag) and NGC 6158 (III 647, 13.7 mag); the last object is already located in Hercules ("discovered with 300 but I could see it very well with the sweeping power"). Figure 2-148 shows the galaxies.

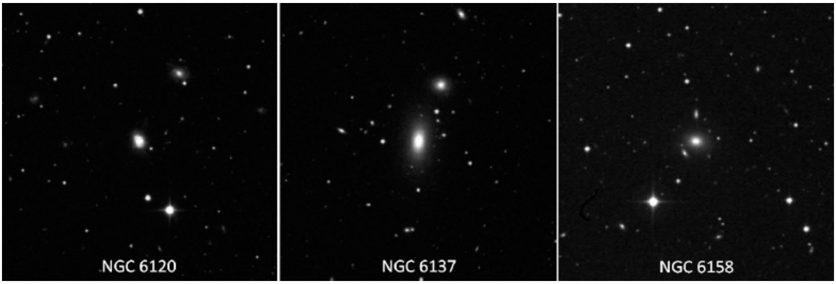


Figure 2-148: Sweeping with 300× on 17 March 1787 brought three galaxies, though the field of view was only 8': NGC 6120 and NGC 6137 in Corona Borealis and NGC 6158 in Hercules (all images 8' × 8').

On 18 March (sweep 716), Herschel discovered the double galaxy NGC 2852/53 (III 629/30) in Lynx, separation 2.2'; it was seen in a single field. Again, 300× was used for a closer look. Nearly a copy (same orientation and distance) was found later that night in sweep 718: NGC 5992/93 (III 635/36) in Boötes. The next find was a planetary nebula in Hercules, NGC 6058 (III 637); the object is faint (13.8 mag) and small (40"). Even with 300× no structure was seen, which led to class III (instead of IV): "2 very close small stars affected with nebulosity; a very small star in the field with it was perfectly free from that nebulosity." The sweep also brought two members of the galaxy cluster Abell 2197 in Hercules (see Table 2-25): NGC 6173 (12.1 mag) and, 11.2' south, NGC 6175 (13.7 mag), catalogued as III 640/41. The latter is an extremely closed double system (separation 11"); of course, Herschel could not resolve the pair.

On 19 March, Herschel had a visitor, whose identity is not known: "Mr. Bryant saw the two Georgian Satellites." The 20-ft observation began at 7:45 pm (before sweep 719). Uranus was in Gemini at 60° altitude. In sweep 720, three 'suspected' objects in Boötes were found. They were not catalogued, but all are galaxies (see Table

5-5). The first two form a pair: IC 944 (13.4 mag) and IC 946 (13.4 mag), distance 9'. Herschel first noticed IC 944 at the western edge of the field of view (AR offset -31^s). A third galaxy, IC 948 (13.2 mag), located at the eastern edge, was not recognized.698 About eight minutes later and 1.4° more north, another object was seen, again at the western edge (AR offset -31^s): "Suspected, very faint, very small, with 300 probably 2 or 3 small stars; just north of a bright star." This is the 13.8 mag galaxy UGC 8902, located 1.2' northeast of an 8.1 mag star. Figure 2-149 shows the three uncatalogued objects.

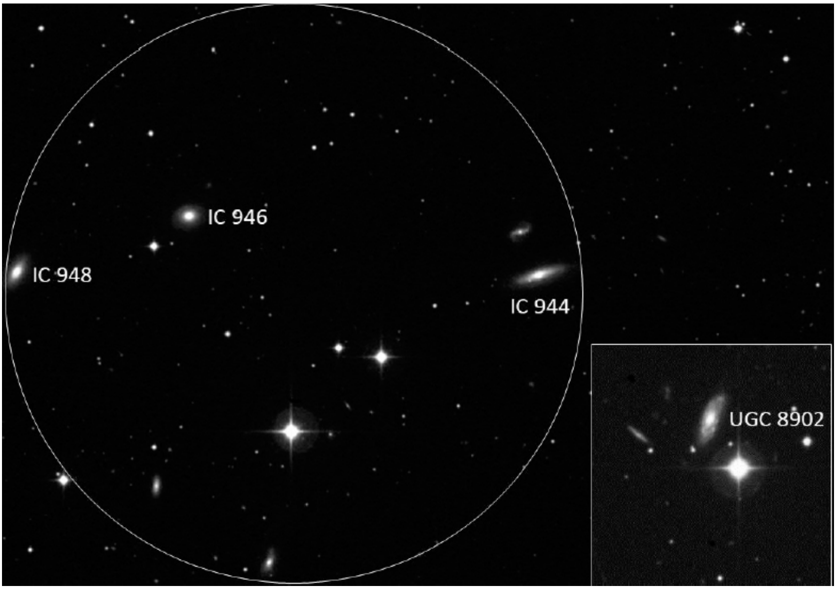


Figure 2-149: Three uncatalogued objects, found on 19 March 1787 in Boötes. The galaxy pair IC 944/46, seen in a single field (15'); IC 948 (13.2 mag) was not perceived. Inset (5' × 5'): the 13.8 mag galaxy UGC 8902 near an 8.1 mag star.

In sweep 722 (20 March), Herschel discovered a pair of double galaxies in Canes Venatici – an extragalactic version of the 'double double' star ε Lyr.699 The first pair consists of the large edge-on galaxy NGC 4627 (II 659) and its much smaller partner NGC 4631 (V 42).700 The two galaxies, 9.2 and 12.4 mag bright and 2.6' distant, were curiously seen in successive fields. Herschel first saw the small companion, then the large nebula: "very bright, much

elongated, from sp to nf, but near the parallel, about 16' long and much brighter middle. A little below the centre is a small star, but probably unconnected."

The second double galaxy was found two minutes later, 33' southeast. The dominating component is NGC 4656 (I 176), also seen edge-on; it has a small appendix, NGC 4657 (I 177), 3.6' northeast.[701] The galaxies, 10.5 mag and 12.4 mag bright, were found in a single field: "Two, their nebulosity join; they are both elongated and both together form a shape of the letter S. The most south considerably bright, much brighter middle. The most north pretty bright, from sp to nf, but very near the meridian." The fascinating cosmic ensemble was never observed again (Figure 2-150).

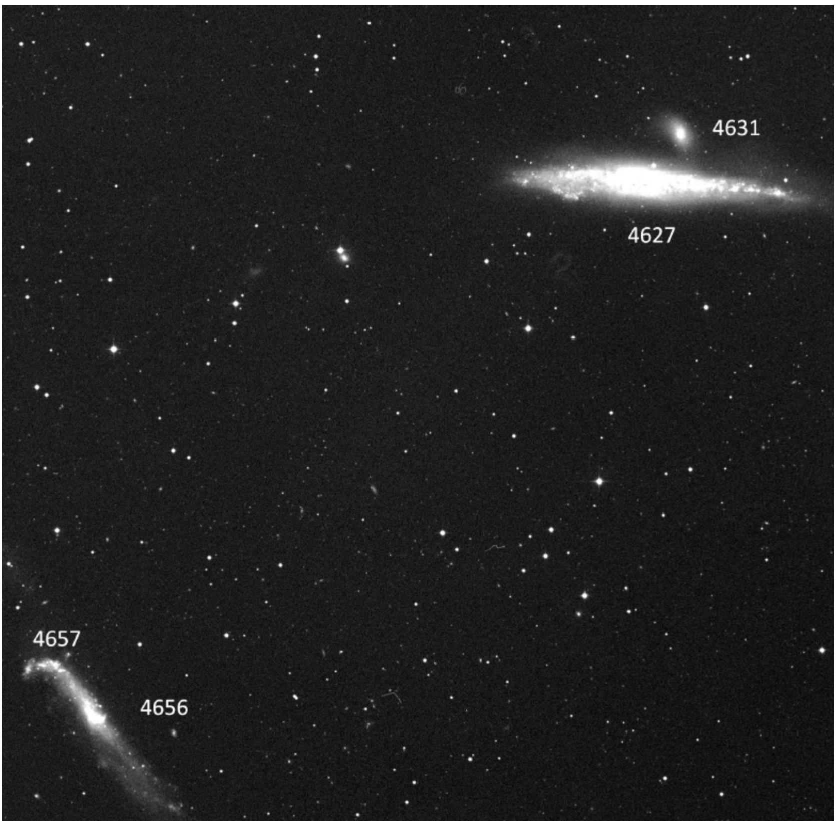


Figure 2-150: Herschel's extragalactic version of the 'double double

star' ε Lyr: NGC 4627/31 and NGC 4656/57 in Canes Venatici (field 35' × 35'). The ensemble is about 28 million light-years distant.

On 9 April (sweep 725), Herschel discovered a curious 'double nebula' in Canes Venatici, seen in a single field: "Two, the most north considerable or very bright. The most south pretty bright. Their nebulosities run into each other." The bright nebulae were catalogued as I 178/79. The place is occupied by the 10.8 mag galaxy NGC 4618, a barred spiral of 'magellanic' type (SBm). A single spiral arm is winding around the main body anti-clockwise to the south. It contains several HII-regions; the two brightest (14.5 and 15.5 mag) were catalogued by Dreyer as IC 3668/69, based on a plate taken by Max Wolf in 1903. There is no doubt that Herschel's 'considerable or bright nebula' I 178 is NGC 4618. But what is the 'pretty bright' nebula south? It cannot be IC 3668, unless Herschel made an error, actually meaning 'pretty faint'. But this is unlikely, due to the remark that "their nebulosities run into each other", implying that I 178/79 are connected. Perhaps he has seen the 1' long bar as a separate object. However, the bar is oriented east-west, rather than north-south.

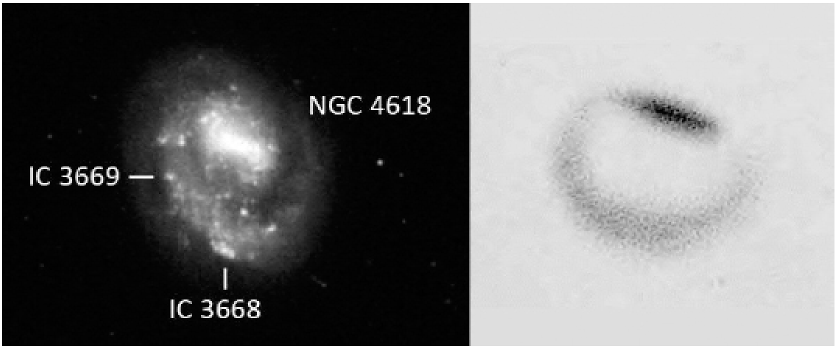


Figure 2-151: The one-armed spiral galaxy NGC 4618, found by Herschel on 9 April 1787 in Canes Venatici. Left: modern image, showing the HII-regions IC 3668/69. Right: Birr Castle drawing of 1856 (the 'bright spots' are not marked).

John has observed I 178/79 on 12 April 1830 (h 1385): "Double; a bright, large nebula, gradually brighter in the middle, with a large faint one attached, 70° south following, so as to run together into one." His 'I 179' is faint, attached and south following. This might

be IC 3668, but is it William's second nebula? Finally, we have the Birr Castle observation (13 April 1855): "Somewhat like h 2055 [NGC 7479]. The south branch is patchy, having 2 bright spots near preceding end. The northern one is much the brighter." The branch is the single spiral arm, resembling that in NGC 7479 (see Figure 2-72). On 27 March 1856 a drawing was made: "the faint branch to the left [east] extends round as far as the preceding extremity of the bright branch." All was seen, the bar, the spiral arm and the HII-regions. We conclude that due to John's observation, it is possible that William has seen IC 3668 too, though his description is misleading.

The sweep in Canes Venatici was performed at high elevations (up to 84°); it brought a total of 35 objects, with some remarkable ones. For instance, the extremely flat 12.3 mag galaxy NGC 5023 (II 664): "much elongated about 5' long ¾' broad, pretty bright from sp to nf". The axis ratio is 9.3, the second highest after NGC 2820 in Ursa Major with 10 (see Table 2-55 and Figure 2-185). A few minutes later, Herschel noted: "Suspected, 300 left it doubtful and shewed 2 small blotted supposed stars." The uncatalogued object is the 13.6 mag galaxy UGC 8756. A similar case appeared in sweep 732 (7 May). When revisiting the 10.8 mag galaxy NGC 5044 (II 531) in Virgo, he noted: "I believe I saw a very faint one". This is correct, there is another galaxy 10.5' southwest: NGC 5035 (12.8 mag). A third case was seen in the next sweep 733 (11 May): "A very faint patch, small a little extended." This is the 14.1 mag galaxy UGC 9598 in Boötes.

An interesting double system was discovered on 11 April in sweep 727. Located about 3° southwest of the globular cluster M 5 (already in Virgo), it consists of the 11.9 mag galaxy NGC 5869 (II 545) and its 13.4 mag companion NGC 5865 (II 684). The objects are 3.6' apart and were seen in a single field (Figure 2-134). Despite the magnitude difference, the objects were both described as "pretty bright, small, irregularly extended". What is so special about the case? Well, the bright component (NGC 5689) was already seen on 24 February 1786 in sweep 532; this explains the difference in the class numbers (II 545, II 684). The faint companion was not mentioned at that time, though it also was in the field. The solution is simple: in the former sweep (532), Herschel still used the

Newtonian focus, whereas in the later one (727), the front-view was applied. The case shows the effectiveness of the new optical design. There are two other examples of pairs, where the fainter component was only seen by the front-view (see Table 2-43).

On 12 April, Herschel had honourable guests at Slough, viewing Uranus in the 20-ft: "Lord Huntingdon saw the Georgian planet but could not perceive the satellites. Lord Rodden saw the planet & one of the satellites but could not perceive the other. Sir Harry saw the planet."[702]

On 19 April, Herschel observed a comet, found by Méchain on the 10th, when it crossed the Pleiades: "Mr. Méchain's comet, nearly round with a small tail towards the nf part. The comet has the same decl. with the foll. star which is south of the two bright southern Pleiades." It might have been a spectacular view: the 4th mag comet, located in front of the bright open cluster.

In sweep 734 (12 May), Herschel viewed M 51 for the first time with the 18.7-inch: "Bright, a very uncommon object. Nebulosity in the center, with a nucleus, surrounded by detached nebulosity in the form of a circle; of unequal brightness in three or four places; forming altogether a most curious object." Immediately after, he 'discovered' the companion, NGC 5195 (I 186), "just north of the former". Curiously, he did not notice his earlier observation, made on 17 September 1783 with the 7-ft. In sweep 734, Herschel also found one of the flattest known galaxies, NGC 5714 (III 625) in Boötes (see Table 2-55 and Figure 2-185). Alas, the object was too faint (13.4 mag) to see the unusual shape ("very faint, irregularly formed, pretty small").

In sweep 735 (same night), Herschel found his globular cluster with the highest declination (+48°): NGC 6229 (IV 50) in Hercules. It is remarkable that the dense 9.5 mag object was put in class IV ('planetary nebulae'):[703] "very bright, round, about 4' diameter. The whole of it is almost equally bright with a faint resolved margin."

On 15 May at 10:52 pm (sweep 736), Herschel reached the zenith. The tube now stood vertically by the bar mechanism. The gallery was at its maximum hight (Figure 2-152).

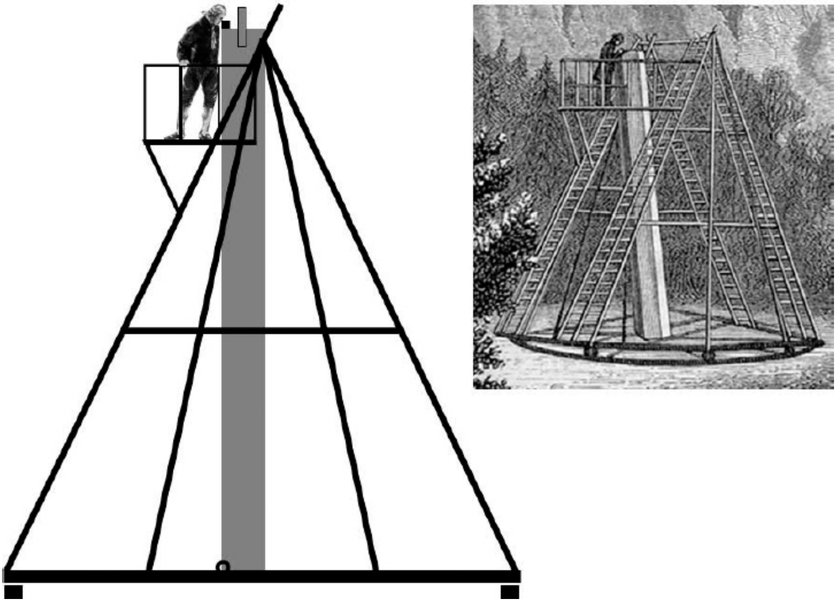


Figure 2-152: For the zenith, the tube end was shifted beyond the centre of the stand. The gallery was at its highest position. The front framework still left space at the top for the ‘sweeping motion’. Right: John, observing near the zenith at Feldhausen (note the front-view).

In the zenith, William discovered the 12.1 mag edge-on galaxy NGC 5673 (II 696) in Boötes (Figure 2-153): “considerably faint, much elongated, from np to sf, pretty large, much brighter middle.” Caroline first used ρ Cep as reference star, which was later changed to “36 Rangifer of Bode’s Cat.” This strange constellation (the reindeer) was located in the Cepheus region. Because of the slow motion, it took one hour until the next object appeared: an unknown 5.8 mag star in Boötes: “7 m, not in Fl, I call it A Bootis”. Caroline later wrote: “This is No. 209 in Cat. of O. stars; and 3 (d) Quadrans Murales of Bode’s Cat. and U[772].” Here she refers to her ‘Catalogue of omitted stars’, listing stars observed by Flamsteed stars, but not inserted in the *British Catalogue*.[704] This is only the introduction. After viewing the star, Herschel noted: “About 3' north and ½ of space [field of view] following is a very faint, very small nebula; and another still fainter and smaller about 7 or 8' following the same star, and about 1' north of it. 300 confirmed it.”

He had discovered the galaxy pair NGC 5797 (III 678) and NGC 5804 (III 679). The companions are 12.8 mag and 13.1 mag bright.

Figure 2-153: In the zenith, Herschel discovered the 12.1 mag edge-on galaxy NGC 5673 in Boötes (15 May 1787).

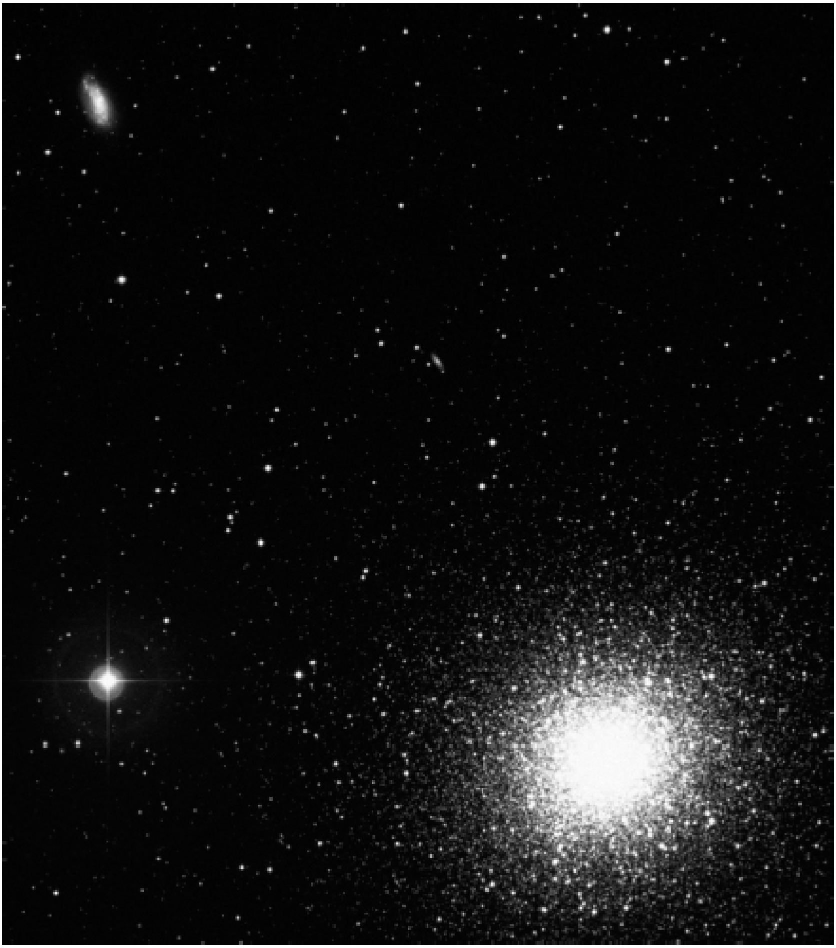


Figure 2-154: On 16 May 1787, Herschel found the galaxy NGC 6207 in Hercules, located only 28' northeast of the bright globular cluster M 13 – an unusual pair. The faint galaxy in between is IC 4617.

Two Messier objects, were seen for the first time in a sweep: the bright globular clusters M 13 and M 92 in Hercules. The views were spectacular. Herschel encountered M 13 on 16 May (sweep 739). Shortly after, a galaxy was found only 28' northeast, NGC 6207 (II 701). The 11.6 mag object was described as “pretty bright, pretty small, elongated from sp to nf.” This is a nice pair of globular cluster and galaxy. M 92 was seen on 11 June (sweep 746) and used as ‘reference star’ for the nebula IV 57, described as “suspected

stellar; but too faint to be verified”. It was observed again on 12 April 1788 (sweep 831): “Faint, stellar or a very small star involved in extremely faint nebulosity.” This brought the object into Herschel’s paper on ‘nebulous stars’, published in 1791.[705] However, IV 57 is the galaxy NGC 6301, superimposed by a 13.8 mag star. A nice planetary nebula was found in sweep 749 on 8 August: NGC 6818 (IV 51) in Sagittarius, known as Little Gem and shining at 9.3 mag. Herschel noted: “A small beautiful planetary nebula, but considerably hazy upon the edges; of a uniform light throughout and considerably bright, 10 or 15" in diameter perfectly round. My brother Jacob being in the Gallery, I shewed it to him.”[706]

On 10 July, two sweeps were made (747, 748). The first, made in Ophiuchus, began in “twilight too strong to see faint objects” and lasted only 10 minutes. After a one-hour break, Herschel continued. In between, a unique event was noted: “40 feet Telescope … A cluster of stars with nebulosity just south following”.[707] Its identity is not known, only the sidereal clock reading is given. Sweep 748 was started in Scutum and soon brought a new double star (N54), with components of 5.7 and 9.3 mag, 12.3" apart. It is in the centre of the large reflection nebula IC 1287, not recognized by Herschel. Two minutes later and 38' northwest an interesting object was seen: “A cluster of very small and pretty compressed stars of variable sizes; but it seems to be of the same nature with the Milky-way which is at a little distance towards the south.” This uncatalogued cluster is NGC 6649 in Scutum.

On 12 August (sweep 750) a single object was found: “exceedingly faint, elongated, from np to sf, about 2' long and 1' broad”, the 12.2 mag galaxy NGC 7171 (III 692) in Aquarius. What is special about it? Only 36' northeast, a unique object was found on 23 September 1846: Neptune. Herschel was too early at the place![708] However, Saturn was in the sweep area that night, but not on the path (ι Aqr was seen, 33' south of the planet).

Between 11 September and 9 November, northern sweeps were made (753, 757–77). After the sweep 758 record there is a note ‘In the North above the Pole’: “The PD piece by leading the string round the barrel the contrary way gives now the real polar distance;

it became necessary to make this alteration as the Telescope now in the descending approaches to the pole and therefore must give decreasing number.” There is also a remark about the field orientation (see Table 2-42): “The Front-view in the north above the pole inverts the preceding and following but not the north and south. This is just the contrary of what happens in the south, as it should be, since the natural view [Newtonian, south] inverts both north and south, and preceding and following.” Caroline later added: “By some later memorandums and directions the terms Top and Bottom have been adopted, and according of this 2nd copy of the sweeps; as had mentioned before. See preface in the 1st volume of this copy.”

In sweep 757 (16 September), Herschel discovered NGC 1184 (II 704) in Cepheus; the 12.4 mag galaxy is among his objects with the highest declination (see Table 3-8). On 19 September, Jacob and Prof. Wilson were present, when a bust of Herschel was taken by Lochée (Figure 2-155).[709] In the night, “Professor Sniadeki saw the Georgian Planet and its two satellites as described. My brother Jacob Herschel saw the same.”[710] The 20-ft was used. Later sweeps 759–761 were made in the north, affected by moonlight, haze and an aurora.

Figure 2-155: Herschel bust, taken by Lochée in 1787; see Turner (1988: G2).

In sweep 762 (10 October) the very red star S Cep was found: “Of a deep orange colour, or pale garnet. Very different from all the stars in this neighbourhood.” The 7.4 mag star was catalogued as U794 (see Table 2-11).[711]

In sweep 765 (14 October), Herschel discovered the bright planetary nebula NGC 7008 (I 192) in Cygnus: “Strong nebulosity of an irregular square figure, seems to contain faint large stars, about 3' long and 2½' broad.” Because the 10.7 mag object did not look like an ordinary ‘planetary nebula’, he put it in class I (‘bright nebulae’). One of the stars inside might be the central star (12.3 mag). The nebula was again observed on 15 and 16 October.

On 18 October, Herschel made an experiment: “This evening I tried to sweep with two eye glasses, one for each eye, at once. The images of the stars are a distinct as in a single eye glass. I expect several considerable advantages from this construction. I tried the same scheme under a different form about two years ago; but it would not answer my end, at that time. It consisted then of an eye glass pavement, as I called it: being several small eye glasses joined in one box serve the same eye, by way of extending the field of view.” The binocular eye-piece was later called ‘double eye glass’. However, for some objects, Herschel changed to the “right eye glass” or “left eye glass”, whichever was more suitable.

The first object in sweep 773 (3 November) was the planetary nebula NGC 7354 (II 705) in Cepheus; the 12.2 mag object appeared “small, pretty bright, almost of an equal light throughout, irregularly round, resolved”. A bit later, Herschel discovered the emission nebula NGC 7538 (II 706): “Very faint nebulosity of 3 or 4' extent, contains two considerable stars, but they do not seem to be connected with it.” A sketch was made, showing two stars, connected by nebulosity (Figure 2-156). The stars have 11.5 mag. The nebula is located only 1.3° west of the bright open cluster M 52 in Cassiopeia.

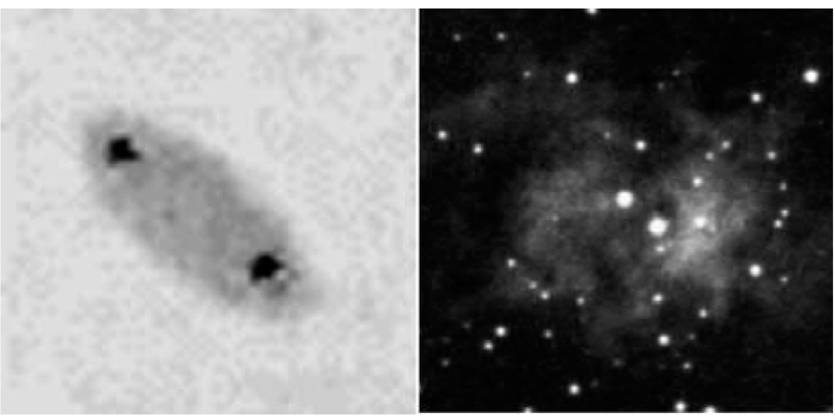


Figure 2-156: The emission nebula NGC 7538 in Cepheus, found on 3 November 1787.

About half an hour later, Herschel encountered “some crouded stars with very faint suspected nebulosity”. He had discovered the

brightest part of the emission nebula LBN 537 in Cepheus. Because the object was not catalogued, it bears no NGC-number (see Table 5-5). Of course, Dreyer noticed uncatalogued objects in the sweep records when preparing the NGC, but refrained from listing them. Nor were they on John's 'working lists', made for the Slough observations. Thus, there was no independent judgment about their identity.

Two minutes after the nebula in Cepheus, Herschel discovered "a bright star with faint nebulosity" and added: "I saw it too late to verify it, as in the north I cannot follow the stars. I rather suspect a deception." This is the 10th mag emission nebula NGC 7635 (IV 52) in Cassiopeia, known as the Bubble Nebula. It was discussed in his paper on nebulous stars of 1791.[712] The remark "I cannot follow the stars" is interesting. Because preceding and following is reversed, the 'side motion' did not work. In the north, the tube could only move to the east (instead of west), which makes no sense. NGC 7635 is located 36' southeast of the open cluster M 52 in Cassiopeia, seen immediately after and for the first time in the 20-ft ("a very beautiful cluster of very compressed stars"). This was also the case for the open cluster M 103 in Cassiopeia. Messier's last object was seen in the same night (sweep 774). A bit later, Herschel discovered the planetary nebula NGC 1501 (IV 53) in Camelopardalis:[713] "A very curious Planetary nebula, near 1' diameter. Round, pretty well defined of a uniform light and pretty bright." The brightness is 11.5 mag; the 14.4 mag central star was too faint. Immediately after, the open cluster NGC 1502 (VII 47) was found 1.4° north.

On 12 November, only a minute after starting sweep 775, Herschel discovered the planetary nebula NGC 7139 (III 696) in Cepheus: "Very faint, irregularly round, may be a patch of stars, but I have not been out long enough, about 1' diameter." Soon after it became cloudy and the sweep was terminated.

After the mission in the north, the telescope was turned back to the south meridian. In sweep 780 (12 November), M 76 in Perseus was observed. With M 91 and M 98, it is the faintest Messier object (10.1 mag). Herschel wrote: "Two close together, their nebulosities run into each other, distance of their centers 1½ or 2' from sp to nf,

both very bright.” Herschel, not knowing about the identity, catalogued both components as I 193. This is indeed one ‘bipolar’ object, known as Little Dumbbell – the little brother of M 27 in Vulpecula. Unfortunately, Dreyer has split the planetary nebula into NGC 650 = M 76 and NGC 651 = I 193.

On 26 November, Herschel entertained some illustrious guests. The planetary nebula NGC 1535 in Eridanus was presented: “I shewed this nebula to Mess^{rs}. Cassini, Méchain, Le Genre & Carochet, but moon light being too bright we did not see it well.”[714] Fortunately, the next night was much better and he could offer some showpieces, starting with the planetary nebula NGC 7662 in Andromeda: “the Moon being absent it appeared in its usual planetary view; these Gentlemen saw it very well and admired it as a great curiosity. Mr. Cassini observed that a very small fixt star nf the nebula appeared not unlike a satellite to it.” We further read: “I shewed the Gentlemen the 15th of the Conaissance des temps resolved into stars. The Moon appearing permitted us not to go on with other objects.” Cassini’s remark about a ‘satellite’ was later discussed as a serious idea (see section 2.8.1). When Herschel saw NGC 7662 again on 3 October 1790, he also had the impression of “a large Planet with a very small Satellite”.

On 30 November (sweep 786), a member of the Local Group was discovered, the 9.2 mag galaxy NGC 185 (II 207) in Cassiopeia, a remote companion of M 31, located 7° south.[715] The very large, pretty bright nebula “seems to be resolvable”. Unfortunately, Herschel missed another member, NGC 147 (9.5 mag), only 1° west of NGC 185. It was not on the sweep path. The area was never visited again. Both galaxies are seen in Figure 2-157. The last discovery of 1787 was made on 3 December in sweep 787: the open cluster NGC 7686 (VIII 69) in Andromeda, also the brightest object found of the year.

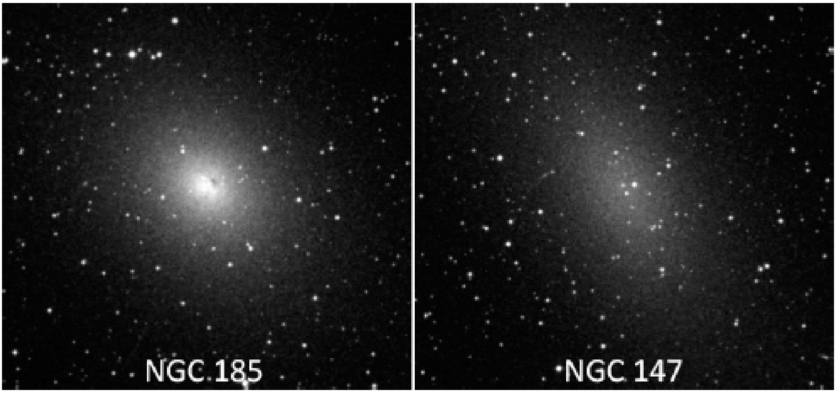


Figure 2-157: On 30 November 1787, Herschel found a Local Group member: NGC 185 in Cassiopeia (left); with 2.3 million light-years, it is his nearest galaxy. NGC 147, another member only 1° west, was missed. Both are remote companions of M 31.

2.6.4. Summary of 1787

Table 2-45 gives the statistical data of the sweeps performed in 1787, starting with no. 676 on 1 January and ending with no. 795 on 13 December. 1787 was the first 'mixed' year. In 20 nights observations were made parallel to the sweeps (recorded in *Journal No. 10B* and *No. 11*). Something similar had only been done in early days of the sweep campaign. A total of 45 nights was dedicated to sweeping only; occasionally, a new eye-piece with 300× and a 'double eye glass' were used. The zenith was reached this year. The Uranian moons Oberon and Titania were discovered with the 20-ft, also Saturn's 6th moon, Enceladus. The 40-ft saw a (provisionally) first light. Caroline opened her 'Temporary index'. In autumn, William and the widow Mary Pitt got engaged.

Category	Value	Remarks
number of nights	66	
longest continuous period (days)	4	17 – 20 March
longest break (days)	29	10 Jul. – 8 Aug. (40-ft construction)
number of sweeps	120	
sweeps per night	7	11 Jan.

(maximum)		
mean night (hours)	3.1	
longest night (hours)	8.3	11 Jan. (observing time 5.9 hours)
lowest elevation (°)	8	15 Mar.
highest elevation (°)	90	PD 39° (15 May)
lowest PD (°)	10	
observed objects	410	
objects per night (mean)	6.2	
sweeps without objects	57	
new objects (all)	255	
uncatalogued objects	13	Table 5-5
re-observed objects	155	
most productive night	14 Jan.	41 objects
new objects: first	11 Jan.	M 33
last	3 Dec.	NGC 7686 (OC And)
brightest (mag)	5.6	NGC 7686 (OC And)
faintest (mag)	14.3	NGC 5003 (Gx CVn)
smallest (")	36	NGC 7354 (PN Cep)
multiple	8	8 pairs
Messier objects:	22	
first observation	4	
first with 20-ft	10	
new stars: double	12	
new garnet stars	1	
star gages	15	
vacant places	20	

Table 2-45: Sweep statistics for 1787.

2.7. Observations in 1788–89

2.7.1. Sweeps, family affairs and Caroline's 2nd comet

The first discovery of the year 1788 was the 11.7 mag edge-on galaxy NGC 3600 (II 709) in Ursa Major, seen on 14 January in

sweep 798. Another edge-on galaxy was found later: NGC 4183 (III 697). The object in Canes Venatici is a bit fainter (12.3 mag) but has an axis ratio of 8; a sketch as made (Figure 2-158).

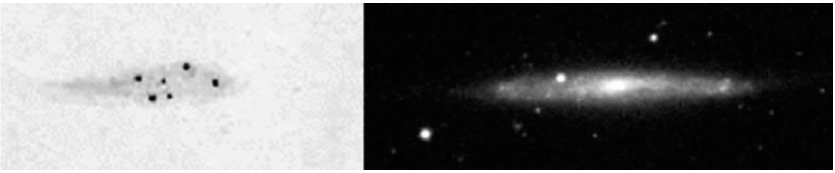


Figure 2-158: The 12.3 mag edge-on galaxy NGC 4183 in Canes Venatici, found on 14 January 1788.

Figure 2-159: The double galaxy NGC 4485/90, located 40' northwest of β CVn, was found on 14 January 1788.

About 15 minutes later, Herschel saw a spectacular double nebula: “Two, the most south very bright, very large, irregularly extended, that to the north bright, pretty large, irregularly formed, about 1½' distance.” These are the interacting galaxies NGC 4485 (I 197) and NGC 4490 (I 198), 11.9 and 9.8 mag bright. The pair is located only 40' northwest of 8 (β) CVn (Figure 2-159).[716] Curiously, the 4.3 mag star is catalogued as NGC 4530! This is due to John Herschel, who viewed it on 1 May 1828: “8 Canum. Involved in a considerable nebula 3' in diameter, exactly round.” The obscure nebula was catalogued as h 1332. The phenomenon was confirmed

in three following observations: “not the least doubt of a considerable nebulous atmosphere round the star” (6 May), “considerable misty” (12 May), ”nebulous” (18 March 1830). It is interesting that β CVn was William’s reference star for NGC 4485/90 in sweep 798. Nothing is mentioned about a surrounding nebula. The case is reminiscent of the non-existent ‘ε Orionis nebula’ V 34 (NGC 1990) of 1 February 1786. Again, John has perceived a ‘nebula’ in this case (h 363): “a very brilliant star involved in an immense nebulous atmosphere” (23 November 1827).[717]

The night of 14 January also brought a trio of 11th mag galaxies in Canes Venatici. Herschel first saw NGC 5350 (II 713) and then, only 4' south, the close pair NGC 5353/54 (II 714/15); the companions are 1.2' apart. A similar trio was found on 3 February (sweep 804) in Ursa Major. There are three 13th mag galaxies in an area of about 6': NGC 3202/05/07 (II 720–22). Though the objects were in a single field, Caroline recorded them separately. All three were seen with an AR offset of -HF = 42^s, i.e. at the western edge (‘half field’ away from the centre).

On 5 February (sweep 807), Herschel saw a “beautiful object” in Lynx, the 9.8 mag edge-on galaxy NGC 2683 (I 200): “Very brilliant, much extended, about 7 or 8' long, and 2½ or 3' broad from sp to nf, but nearer the meridian. The brightness also much extended and going off pretty suddenly.” It is interesting that the object was not catalogued as ‘large nebula’, as done for similar sizes; obviously, the factor brightness (“very brilliant”) was more important.

On 6 February (sweep 809), Herschel discovered NGC 2537 (IV 55) in Lynx. The 11.7 mag object is known as the Bear Paw Galaxy. Being not sure about its nature, he put it in class IV. The object was again seen on 10 March in sweep 817: “Pretty bright, round, almost of an even light throughout, approaching to a planetary but very ill defined, and a little fainter on the edges, about ¾ or 1' diameter.” Though on the sweep path on both dates, he missed the superthin galaxy IC 2233, 17' southeast.[718] Both objects are shown in Figure 2-160.

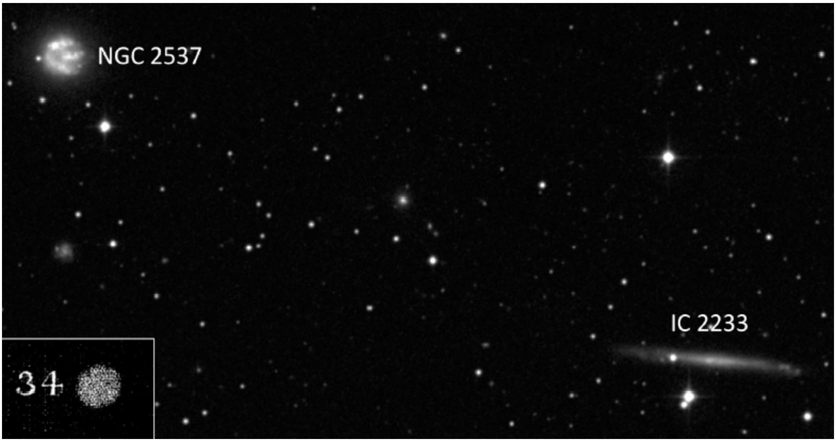


Figure 2-160: Two peculiar objects in Lynx. The Bear Paw Galaxy NGC 2537 was found by Herschel on 6 February 1788; on 10 March, a sketch was made (inset). Alas, the superthin galaxy IC 2233, 17' southeast, was missed (north is left).

In sweep 813 (4 March), William encountered an unknown 6.7 mag star (U[809]). In Caroline's sweep revision, it is identified in Bode's catalogue as '34 Telescopii Herschelii". Thus, he saw a star in his telescope that is in the appropriate constellation. Maximilian Hell had created it in 1789 to honour the Uranus discovery.[719] Originally the constellation was named 'Tubus Hershelli Major' and depicted the 20-ft; its little brother was 'Tubus Hershelli Minor' (7-ft). The two celestial telescopes were located near ζ Tau, i.e. in the discovery region. In the *Uranographia* of 1801, Bode renamed the former 'Telescopium Herschelii' (the other was omitted), now showing the 7-ft (Figure 2-161). Since the revision of the constellations in 1922 (rejecting strange cases), the region belongs to Auriga.

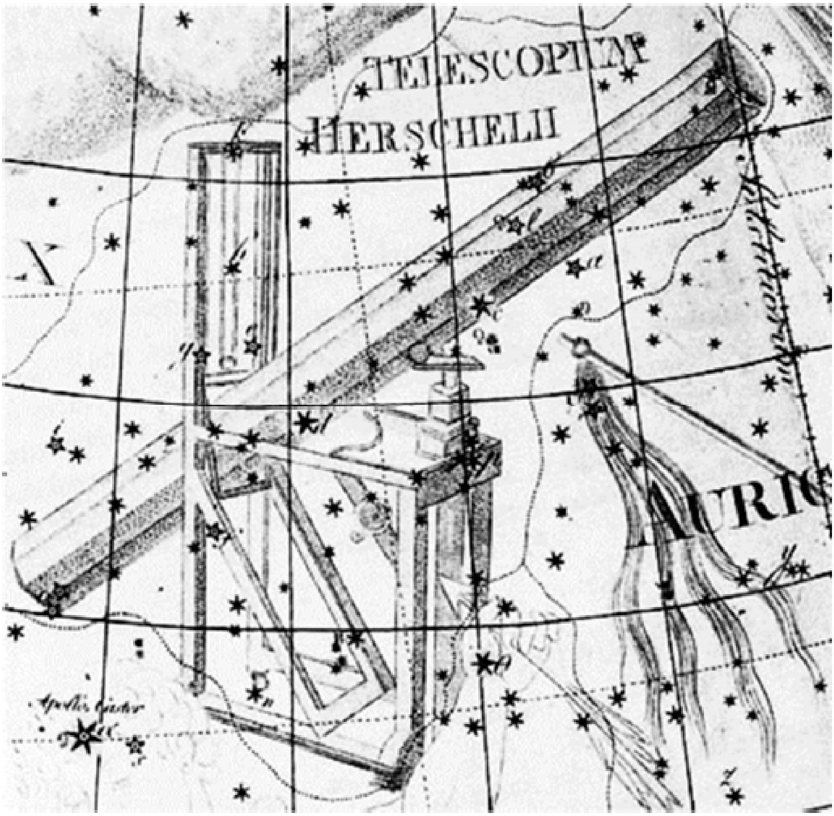


Figure 2-161: The constellation ‘Telescopium Herschelii’ in Bode’s *Uranographia* of 1801.

On 9 March (sweep 815), Herschel discovered a bright spiral galaxy very near the zenith: NGC 2841 (I 205) in Ursa Major. The 9.6 mag object was described as: “Very bright, large bright nucleus, with chevelure and branches; and milky nebulosity about 5 or 6' long, 3 or 4' broad.” A sketch was made (Figure 2-162). An even brighter galaxy was found a bit later in sweep 816: the ‘large nebula’ V 43 in Canes Venatici. This is the 8.4 mag galaxy NGC 4258, discovered by Méchain in July 1781. The object was later added to the *Messier Catalogue* as M 106. Herschel wrote: “Very brilliant, bright nucleus with many faint branches from np to sf about 15' long and to the sf running out with very faint nebulosity. Extending a great way.” Here, too, the ‘branches’ are not the spiral arms that even Lord Rosse, with his 72 inches, has not seen.

On the 11th, Herschel had two guests, which were invited to look through the 18.7-inch reflector after sweep 821: “Dr. Watson and Mr. Marsden saw the satellites of the Georgian Planet in the place my calculations represent them. […] I shewed them the planetary Nebula preceding b Crateris; and the 3rd of the Conaiss. des temps [M 3] resolved into stars.” The planetary nebula is NGC 3242 in Hydra.[720]

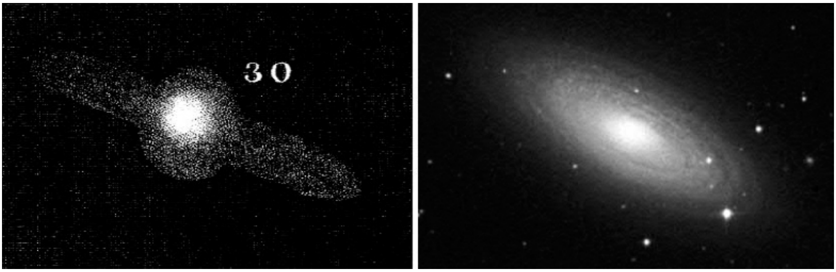


Figure 2-162: The elongated 9.6 mag galaxy NGC 2841 in Ursa Major, discovered on 9 March 1788.

On 8 April, Herschel had an interesting guest, joining his observation of the Moon, probably made with the 7-ft: “The Volcano of (Mons porphyrites) is considerably bright, and confined to a pretty small point. The Bishop of Landaff saw the lunar formation, compared it to the size of a pea.”[721]

In sweep 833 (27 April), William found a peculiar nebula in Canes Venatici: ”Very brilliant, considerably large, difficultly resolved, extended from sp to nf, seems to have 3 or 4 bright nuclei.” This is the irregular 9.6 mag galaxy NGC 4449 (I 213), peppered with bright HII-regions. The sketch shows four of them (Figure 2-163). He included the object in his paper of ‘nebulous stars’ of 1791. It is interesting that Caroline independently found the nebula on 8 July 1793 with the large sweeper. 18 minutes later, William saw a “deep red” star in the same constellation (U^{817}). This is Y CVn, known as La Superba (see Table 2-11).[722] In sweep 834 (the same night), a close double galaxy was found in Boötes, catalogued as II 751/52. This is NGC 5857/59; the companions are seen nearly edge-on with the same position angle (distance 2').

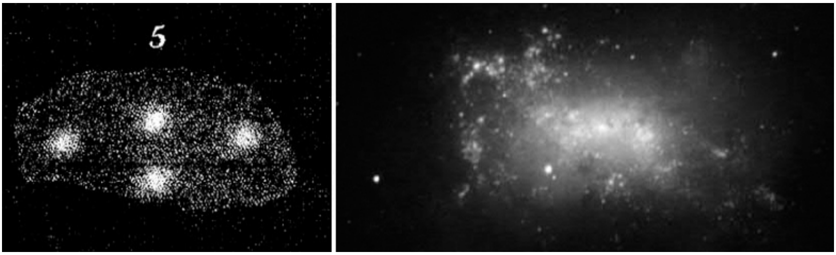


Figure 2-163: The irregular 9.6 mag galaxy NGC 4449 in Canes Venatici; Herschel’s sketch, made on 27 April 1788, shows four ‘bright nuclei’ (HII-regions).

Sweeps 840–48 were made in the north, above the pole. On 1 May (sweep 840), Herschel encountered a 10.8 mag galaxy with asymmetric nucleus: NGC 5474 (I 214) in Ursa Major, worth a sketch (Figure 2-164). It shows a star with a fan-shaped extension: “Considerably bright, terminating abruptly to the north, and diffused to the south, considerably large.” On the 3rd, Herschel wrote: “I tried the Double eye glass better executed than before; by having made room for the nose between, so far easily to come at the proper focus of pencils with each eye, and find it to act so well, that I suppose I shall continue it.” The tool, introduced on 18 October 1787 in sweep 769, was used in sweeps 842–46.

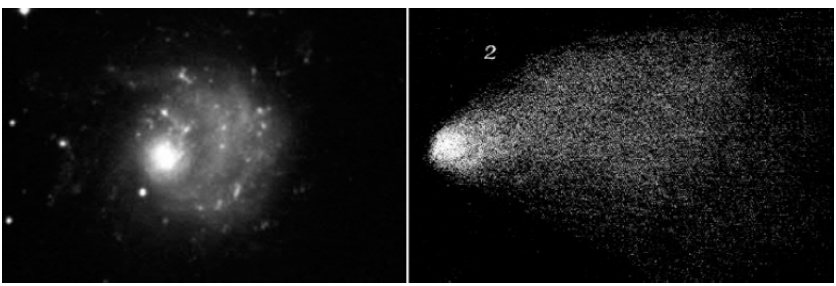


Figure 2-164: The asymmetric 10.8 mag galaxy NGC 5474 in Ursa Major, sketched by Herschel on 1 May 1788.

In sweep 842 (5 May), Herschel independently found M 102 in Draco (I 215). The 9.9 mag galaxy (NGC 5866) had been discovered by Méchain in March 1781. The sweep brought a total of seven nebulae (all new). Curiously, he took the third, NGC 5879 (II 757), as the ‘reference star’, because there was no suitable one in the area

(see Table 2-27). The position of II 757 was determined in the next sweep (843) on 25 May by the star ι Dra, located 2.8° northeast. The nebula was now at the bottom of the sweep. The night of 5 May also brought a festival of four edge-on galaxies in Draco. The first is the most spectacular: the large 10.3 mag NGC 5907 (II 759) with an axis ratio of 9 (see Figure 2-185). About 18 minutes later, the 11.7 mag galaxy NGC 5965 (II 762) followed; axis ratio 6. In the next sweep (843), Herschel discovered the 13th mag galaxies NGC 5894 (II 763) and NGC 5981 with axis ratios of 7.5 and 9, respectively. The latter is the westernmost member of a 15' long chain of three galaxies, roughly oriented east-west (Figure 2-165). It contains NGC 5981, NGC 5982 (II 764) and NGC 5985 (II 766). Herschel noted for II 764: “Pretty bright, small, irregular round. A very faint suspected preceding, little extended.” The suspected nebula is NGC 5981 (not catalogued). The third (II 766) was seen in the next field. NGC 5907 and NGC 5981 are among the flattest galaxies, found by Herschel (see Table 2-55).

Figure 2-165: The ‘Draco chain’, spanning over 15', consists of the extremely flat galaxy NGC 5981 (13.0 mag), the elliptical galaxy NGC 5982 (11.1 mag) and the spiral NGC 5985 (11.1 mag). Herschel found the remarkable trio on 15 May 1788.

However, the northern mission was interrupted; there is a break of 20 days between sweep 843 (5 May) and 844 (25 May). The reason is simple, 50-year-old William had married his neighbour, the rich widow Mary Pitt, at the age of 38.[723] His financial problems were

now over. Caroline was not amused – she left the house and moved to the cottage ("I gave up my place as a housekeeper"). Her rooms were on the first floor, above William's workshop (see Figure 2-123). An even longer break (29 days) appeared between sweep 848 (9 June) and 849 (8 July).

Sweep 849 brought the 13.4 mag planetary nebula NGC 6742 (II 742) in Draco: "Very faint, stellar, 300 verified it." On the 30th (sweep 850), William 'discovered' one of Caroline's objects: NGC 6633 (VII 72) in Ophiuchus. The bright open cluster (4.6 mag) was already seen on 31 July 1783. The siblings did not notice the identity. A bit later, an annular nebula was found in Aquila. However, William only saw a "considerably faint, irregularly round, resolvable" object (III 743). This is the 11.4 mag planetary nebula NGC 6781 (diameter 2').[724] John wrote on 18 March 1830: "A most beautiful, very large, faint planetary nebula. Diameter 1' 37"; its light nearly uniform, only very little hazy at the edge and perhaps rather brighter at the southern limb. Its nature seems to have been overlooked or mistaken by my Father, who has placed it in the third class. In Milky Way. Many stars in field, one 11 m near the north following limb."

On 2 August (before sweep 851) "The Revd. Mr. Wollaston saw some of the Nebulae of the Connoissance des temps resolved." In the next night "Lord Palmerston saw a planetary Nebula, and many of the Connaiss. des temps resolved." It is not known, which objects were presented. The queue of visitors continued. On the 5th, "Mr. De la Lande observed a few minutes". Later (sweep 853) the French astronomer "saw this Nebula [NGC 6818 in Sagittarius], having never before seen a planetary one". Finally, for the 6th we read: "I shewed Mr. Pigott Jr. the Nebula in Hercules resolved into stars, and my Planetary Nebula near the 13th Andromeda." The show pieces were M 13 and NGC 7662. Wollaston and Piggott are shown in Figure 2-166.

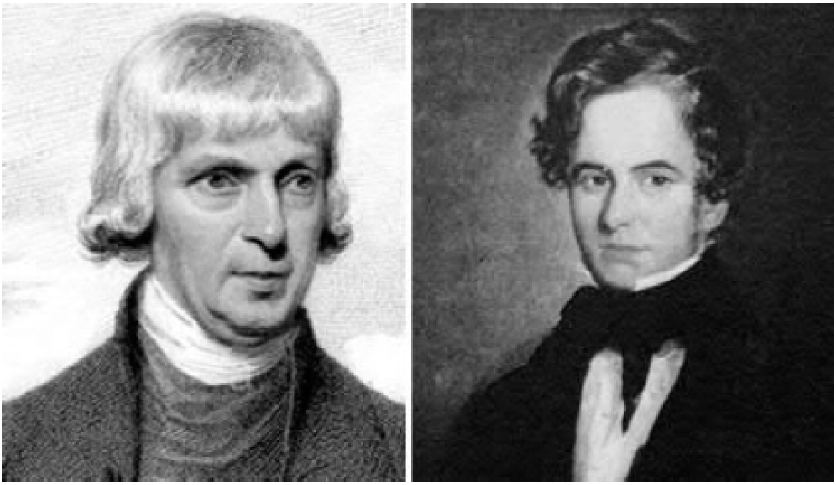


Figure 2-166: Guests at Slough: Francis Wollaston (left), author of an important star catalogue, and Edward Pigott, well-known for his observations of variable stars.

In sweep 866 (27 September), William saw a star "A large star surrounded with many considerable stars, forming a brilliant though much scattered cluster; the star 6 m is not in the center but towards the following side." Caroline could not find the star in the *British Catalogue*; it is V2140 Cyg with 5.8 mag (the variability is only 0.1 mag). It illuminates the faint reflection nebula IC 5076. However, William only saw the open cluster, catalogued as VIII 76. In September 1829, John made two observations. Although Caroline's position in the *Zone Catalogue* is fine, another cluster (h 2091) was recorded, about 14' southwest. John, lists the object as GC 4615 in his *General Catalogue*. Dreyer followed him and catalogued the open cluster as NGC 6991. In the literature, we find NGC 6991 n two variants: 'WH's cluster' and 'JH's cluster', but only the latter is the NGC object. Later in the night of the 27th, Herschel viewed the large, bright open cluster M 39 in Cygnus for the first time with the 20-ft – and was a bit frustrated: "The 39th of the Connaiss. des temps consists of such large and stragling stars, that I could not tell where it began nor where it ended. It cannot be called a cluster."

On 1 November (sweep 877), Herschel saw the Double Cluster in Perseus (NGC 869/84): "very beautiful brilliant". Curiously, not

remembering his two observations in August 1780 with the 6.2-inch, he though both objects to be new and catalogued them as VI 33 and VI 34.

The sweeps 874–894 between 30 October and 18 December were again made in the north, above the pole. On 1 November (sweep 879) Herschel observed at PD 24° ($\delta = 66°$), writing: “The motion being so slow I put on the glass [eye-piece] which give the instrument a power of 300.” With increasing declination, the sky motion, visible in the field of view, becomes slower (Figure 2-167). For $\delta = 66°$ an object needs 2.5 minutes to cross the standard field of 15' at 157×. This was too slow, so he tried the eyes-piece for 300×, giving a field of 8'. The change reduced the time to 1.3 minutes. After five minutes, Herschel “took the common glass [157×] again” and saw a considerably bright nebula of “6 or 7' diameter resembling a star with a misty atmosphere”.725 This is the 8.5 mag galaxy NGC 2403 (V 44) in Camelopardalis.726 The ‘large nebula’ was again observed in sweep 889 (3 December), now showing “very faint branches extending great way. To the np side I could trace the branch about half a degree; and to the north, or nf, the Nebulosity was diffused over a considerable space, I am pretty sure not less than a whole degree.” Actually, NGC 2403 was Herschel’s largest galaxy.727

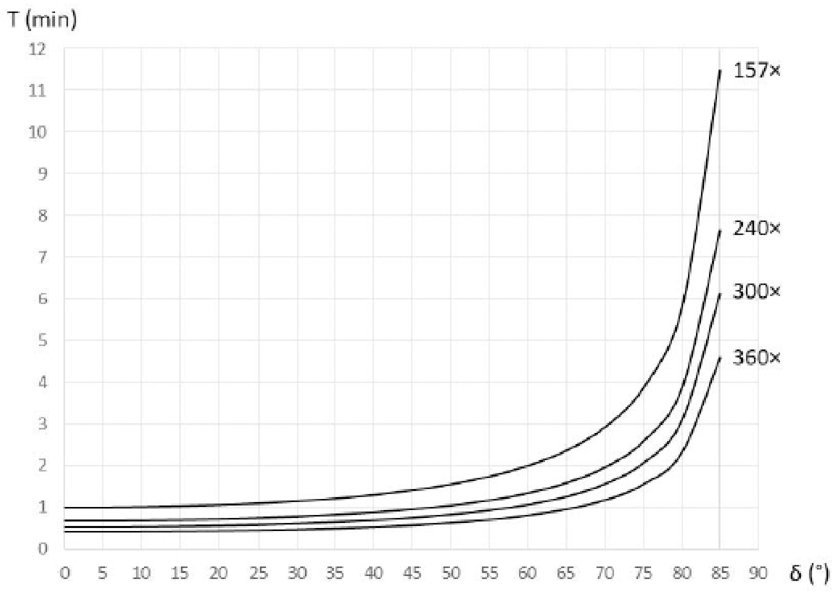


Figure 2-167: The time for an object to cross the field of view due to the sky motion depends on declination (independent of the sign). The four curves refer to Herschel's main eye-pieces and their power (see Table 2-50).

On 24 & 28 October and 23 November 1788, tests were made with the 40-ft. On the first date, Saturn was observed at 8:15 pm. For the second we read: "By way of trying the motions I began to sweep. The PD piece, the speaking pipe, the hanging seat, and all the movements acted extremely well. The commodity of observing with this instrument is far beyond what I ever had before." It soon became cloudy and the first trial sweep was not registered. Herschel was not satisfied with the optical image: "The small stars are not yet brought to a small point, as they are in the 20-ft Speculum." For sweeping, he used an eye-piece which gave field of view of 9.1' at 280 ×. 23 November brought a second trial sweep with a breadth of 2° 35', lasting only 20 minutes. The night was very unusual. It began at 6:30 pm with sweep 883 in the north, above the pole, and ended at 8:15 pm in Cassiopeia (elevation 78°). Herschel now changed to the 40-ft, making the only documented observation in the north! The test sweep started at 10 pm and lasted only 20 minutes. The tube had an elevation of 87°, pointing to Perseus (above the pole)! He noted: "The heavens considerably rich in stars of all sizes." Then he returned to the 20-ft for sweep 884; it started at 11.35 pm, lasting half an hour. A region in Camelopardalis was observed (above the pole).

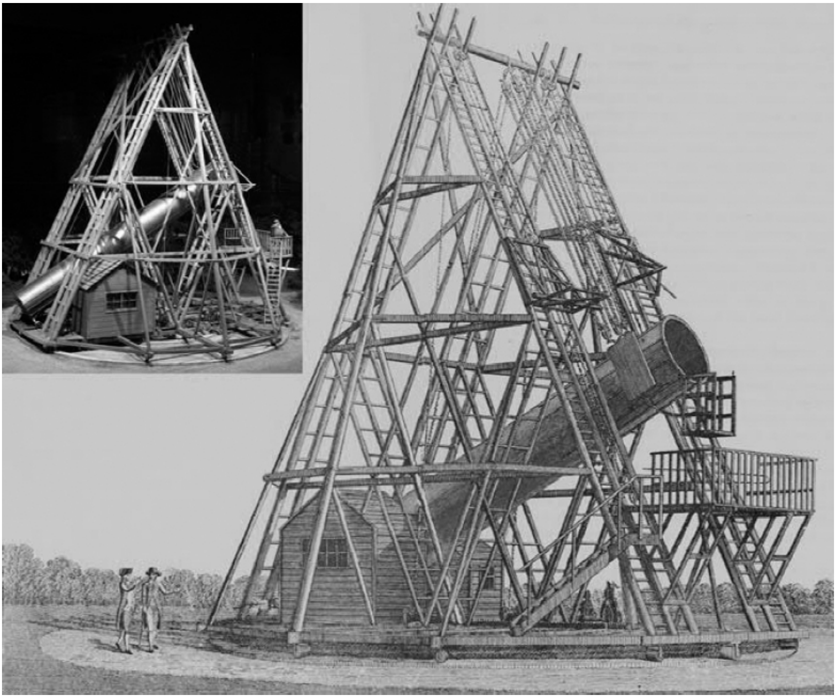


Figure 2-168: The 40-ft reflector at Slough; inset: model on display at *Deutsches Museum*, München.

For the 20-ft, 1 November marked a new era. In sweep 878, William used reference stars, which were not listed in the *British Catalogue*. Caroline had received proof sheets of Wollaston's new star catalogue (it was to appear in 1789). The work is a revision and extension of Flamsteed's catalogue, including stars observed by Tobias Mayer, Lacaille and Hevelius, with 1790 positions. Gaps in the polar region could now be filled. The first Wollaston stars were 7, 13 and 17 Camelopardalis Hevelii. From now on, the positions were calculated for 1790.

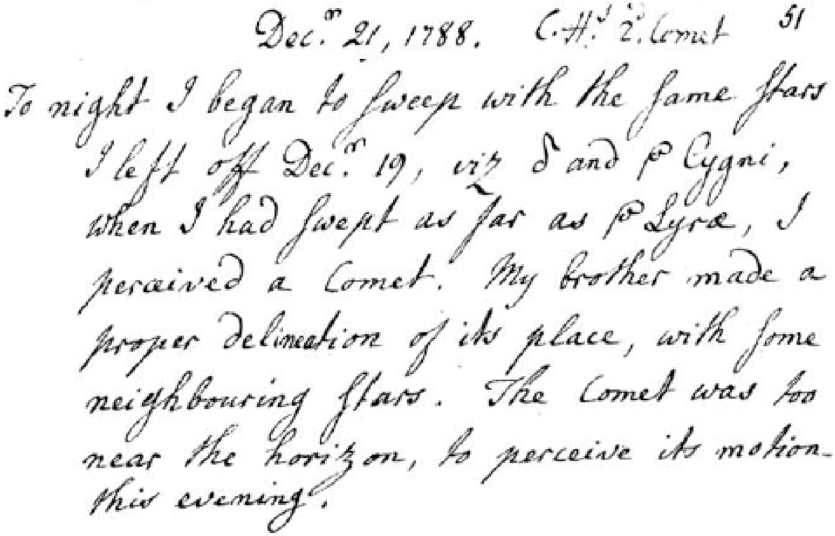
On 4 November (sweep 881), Herschel discovered his second nearest galaxy: NGC 1569 (II 768) in Camelopardalis.[728] With 9.5 million light-years, the 11.0 mag irregular galaxy is located just outside the Local Group. He wrote: "Pretty bright, large extended, bright nucleus, small, just outside a pretty bright star." The 9.7 mag star is 55" north of the centre.

In sweep 883 (23 November), Herschel discovered NGC 7762 (VII 55) in Cepheus; it is his open cluster with the highest declination (+67°). On 25 November (sweep 886), he also found his most north planetary nebula: NGC 40 (IV 58) in Cepheus at $\delta = +71°$.[729] He noted about the 12.3 mag object: "A star about 9m, surrounded with very faint nebulosity; other stars of the same size are perfectly free from that appearance. The star is either not round or Double; but having no motion to follow when I am in the north and above the pole, I could not view it sufficiently to determine it. Less than 1' in diameter." The 'star' is in fact the 11.5 mag central star of the planetary. NGC 40 is discussed in Herschel's 1791 publication on 'nebulous stars'. In the following night (sweep 887), he encountered "A small cluster pf very faint stars exceedingly compressed stars about 1' diameter. The next step to an easily resolvable nebula". This is the open cluster NGC 136 (VI 35) in Cassiopeia.

On 3 December (sweep 889), Herschel discovered an object to be entered as no. 2000 in Caroline's 'General catalogue': the 11th mag galaxy NGC 1962 (III 747) in Camelopardalis. 13 minutes later, an uncatalogued object followed: "2 very faint stars with exceedingly faint nebulosity between them; but the nebulosity doubtful." The pair was listed as U^{871} and U^{872}. Actually, this is 13.9 mag galaxy UGC 3580. The next object is also remarkable: "very faint, very small, stellar, 300 confirmed it, and shewed a very faint branch to the nf side." Here we have the irregular 11.1 mag galaxy NGC 2366 (III 748), showing some scattered HII-regions. Herschel has seen the brightest in the southwestern part of the galaxy and a fainter one to the northeast ("branch to the nf side").[730]

On 8 December, Caroline tried to find a comet, found by Messier on 26 November. Though her search was in vain, the observation was remarkable:[731] "Another night of unavailing search, with thermometer 20° [Fahrenheit]." At -7°C the ink was frozen. This occasionally happened in winter sweeps, hindering the writing. If not Messier's comet, then her own. On the 21st, Caroline found her second comet, again with the small sweeper.[732] The 7th mag object was seen about 8 pm in Lyra, located only 13° above the north-western horizon. Her record is shown in Figure 2-169.[733] Half an hour later, William saw the comet in the 10-ft and made a sketch. At 11 pm, the siblings started sweep 897, inspecting areas in Auriga

and Lynx. William observed the comet the next two days, then he began to sweep again (898).


Dec.r 21, 1788. C.H.s 2.d Comet 51

To night I began to sweep with the same stars I left off Dec.r 19, viz δ and ρ Cygni, when I had swept as far as ρ Lyrae, I perceived a Comet. My brother made a proper delineation of its place, with some neighbouring stars. The Comet was too near the horizon, to perceive its motion this evening.

Figure 2-169: Discovery record of Caroline's 2nd comet. It was found on 21 December 1788 with the small sweeper.

On 14 January 1789, Caroline noted in her observing book: "I swept that part of the heavens between the head of Pegasus, and α Piscium down to the horizon; but it was not clear in the lower part of the sweep. Fomalhaut was hardly visible all the time during this sweep. […] this last sweep was made in pursuit of the great Comet." Caroline marked the comet, seen near 82 Peg, in the *Atlas Coelestis* by 'Com' (Figure 2-170). However, not her second comet is meant here. The record concerns the object, found by Messier on 16 November 1788. Since 8 December 1788 she was searching for it in vain ("I could find nothing"). Perhaps the position was incorrect – as it likely was on 14 January. Messier's comet was 4° southwest of the mark and the brightness had already fallen to 10th magnitude – too faint for Caroline's small sweeper.

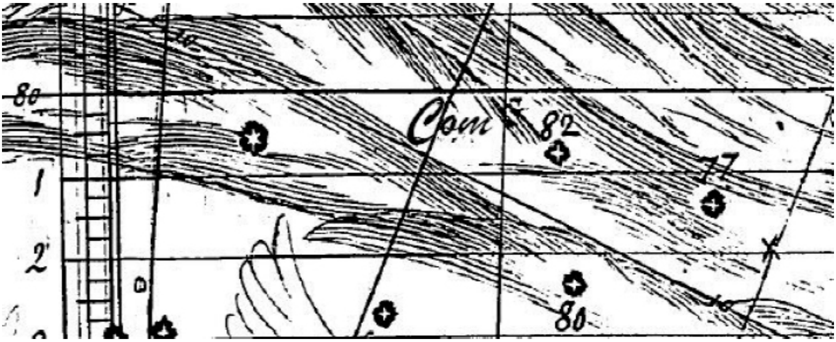


Figure 2-170: Caroline's mark on the *Atlas Coelestis* of a comet near 82 Peg, observed on 14 January 1789.[734]

In sweep 899 on the 27th, Herschel found a bright reflection nebula in Perseus, NGC 1579 (I 217), described it as 'cometic'. The object was seen again in sweep 1057 (2 January 1794). Finally, three sweeps (901–903) were made on New Year's Eve. A remarkable object was found in the first: NGC 2419 (I 218). This is a remote globular cluster, known as the Intergalactic Wanderer. The 10.3 mag object is located in Lynx. Due to the great distance of 269,000 light-years, it appears very small and compressed.[735] Because there was no catalogued reference star, the 'unknown' 7.2 mag star 3.2' west of the cluster was used (U^{379}). When Caroline later revised the sweep data, she identified it as "76 (i) Telecopii Herschelii of B's Cat.". Bode's *Uranographia* dedicates the eastern part of Lynx to Herschel. NGC 2419 was his last globular cluster discovery.

2.7.2. Sweeping with the 20- and the 40-ft

The year 1789 started with a new 20-ft mirror. On 20 January (sweep 904), Herschel wrote: "This evening I tried a new Speculum polished by a Machine; it is not quite finished but promises to be very excellent." On 22 February (sweep 906) it was praised as "very fine". In this "extremely windy" night, Uranus and his two satellites were seen and sketched, located only 3° east of M 44 (sweep 907).

Nothing remarkable was seen until 20 March (sweep 913) when Herschel found an interesting double galaxy in a single field: "Two, both very faint, very small, extended, within 1½' of each other." The pair in Virgo is NGC 4403/04 (III 755/56), both 12.7 mag

bright. With a separation of only 53", the double galaxy is among his closest (see Figure 2-101 and Table 2-28).

On 23 March (sweep 915), Herschel saw a perfectly round nebula in Ursa Major: "nucleus considerably well defined, and the chevelure very faint". This is the 12.2 mag galaxy NGC 3958 (IV 59), listed in the paper on 'nebulous stars' of 1791. About 15' northeast, NGC 3665 (I 219), a 10.3 mag companion was seen and sketched.[736]

Sweeps 919–931, lasting from 12 April to 14 May, were again made in the north above the pole. In the first, Herschel discovered the 10.8 mag galaxy NGC 3310 in Ursa Major, catalogued as 'planetary nebula' IV 60: "Very bright, round, planetary, but very ill defined. About 1' diameter of it is equally bright, and ¼ of a minute hazy or ill defined round the margin." In the same sweep, he saw the 9.8 mag galaxy M 109 (NGC 3992) in Ursa Major. The added Messier object was discovered by Méchain on 12 March 1781. Herschel noticed "branches about 30° np to sf"; again, this feature does not mean spiral arms, but is due to the 45° inclination. The galaxy was observed a second time on 14 April (sweep 920). On 17 April, Herschel discovered his galaxy with the second largest distance: NGC 4199 (III 797) in Ursa Major. The 14.3 mag object is 827 million light-years away.[737]

On 13 April, 'Abbe Ximenes from Spain' visited Slough:[738] "[He] saw the planetary Nebula near b Crateris (746); the 53rd and 67th of the Conoiss. des temps and the Georgian Planet. With the 7 feet too, he saw Jupiter; double stars etc." The planetary nebula is NGC 3242 in Hydra. Another guest appeared on the 14th; sweep 920 was interrupted: "I left off a few minutes to let Lord Bulkeley look, and when I looked in again saw the following Nebula. In going down Ld. B. disturbed the PD line."[739] Later that night, when Herschel continued sweeping, he had his first view of the 9.9 mag planetary nebula M 97 in Ursa Major: "Round, 3' diameter of an equal light throughout, very or considerably bright like a planetary brought to ¼ of the distance of my other planetary ones; it has an ill defined margin of no great extent." The remarkable object was seen again on 24 April (sweep 925). In Lord Rosse's drawing of 1850, M 97 appears like the head of an owl, which led to the common name Owl Nebula.[740] Immediately after M 97, the 13.7 mag galaxy NGC

3594 (III 770) was found; it forms a nice triangle with M 97 an M 108 (Figure 2-171).

14 December (sweep 921) brought the 11.9 mag edge-on galaxy NGC 5422 (I 230) in Ursa Major ("faint branches from sp to nf"). Then followed another highlight from the *Messier Catalogue*, M 101: "A very bright small nucleus with extensive nebulosity, pretty well determined on the preceding side but very diffused to the north-following; include the two following Nebulae, and seems to extend 20' perhaps 30' or more." The "two following Nebulae" are NGC 5461 (III 788) and NGC 5462 (III 789). These are bright HII-regions, seen as nebular knots in the large face-on galaxy. Actually, the object found by Herschel shortly before M 101, NGC 5447 (III 787), also belongs to it; see Figure 2-172. The three are among Herschel's eight galaxy parts, which mainly are HII-regions (Table 2-46).

NGC	H	Sw	Date	V	Con	Gx	Remarks
604	III 150	266	11 Sep. 1784	12.0	Tri	M 33	HII-region
206	V 36	282	5 Oct. 1784	14.0	And	M 31	super star cluster
2905	I 57	318	16 Nov. 1784	13.3	Leo	NGC 2903	HII-region
4657	I 177	722	20 Mar. 1787	12.4	CVn	NGC 4656	HII-region
IC 3668	I 179	725	9 Apr. 1787	13.0	CVn	NGC 4618	HII-region, doubtful
5447	III 787	921	14 Apr. 1789	13.5	UMa	M 101	HII-region
5461	III 788	921	14 Apr. 1789	14.0	UMa	M 101	HII-region
5462	III 789	921	14 Apr. 1789	13.5	UMa	M 101	HII-region

Table 2-46: Parts of galaxies (GxP), discovered by Herschel during the sweeps; most of them are bright HII-regions.

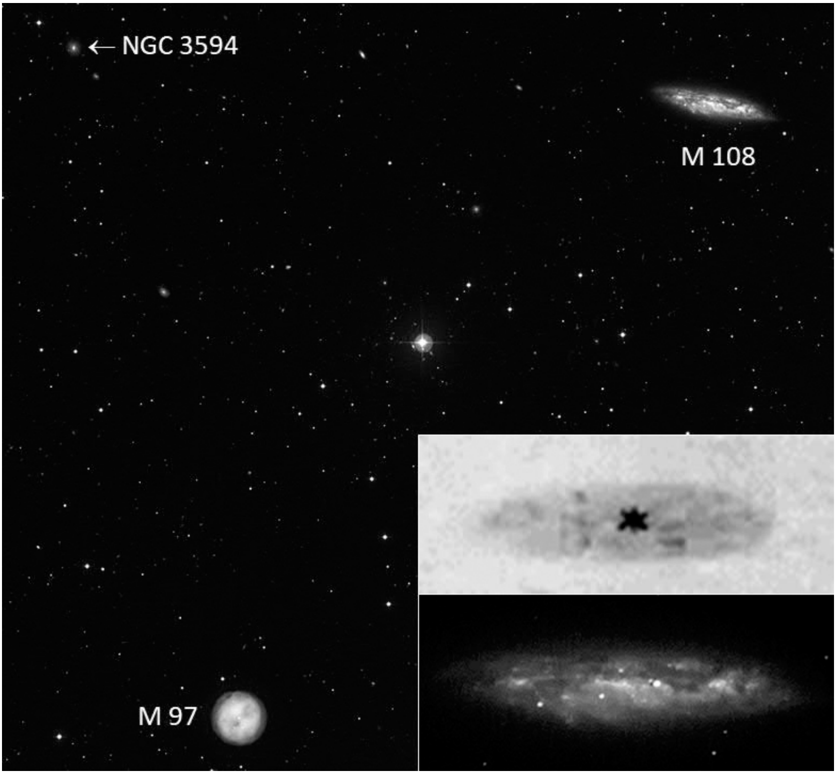


Figure 2-171: M 97 and the stellar galaxy NGC 3594 were seen on 13 April 1789. Together with M 108, found on the 17^{th}, they form a nice triangle in Ursa Major. Inset: Herschel's drawing of M 108 shows the 12.8 mag superimposed star, sometimes misinterpreted as a 'supernova' (seen also in the image below).

In sweep 922 (17 April), Herschel found M 108 (NGC 3556) in Ursa Major, described as: "Very bright, 10' long 2' broad, an unconnected pretty bright star in the middle, resolved." The 10.0 mag edge-on galaxy was catalogued as 'large nebula' V 46. M 108 was already discovered by Méchain on 16 February 1781, which was unknown to Herschel. The galaxy was added to the *Messier Catalogue* in 1954 by the Harvard astronomer Owen Gingerich. Herschel's sketch, made in the night of the 17^{th}, shows a remarkable 'central star' (Figure 2-171). The 12.8 mag object was sometimes mistaken for a supernova.[741] M 108 was seen a last time on 24 April in sweep 925.

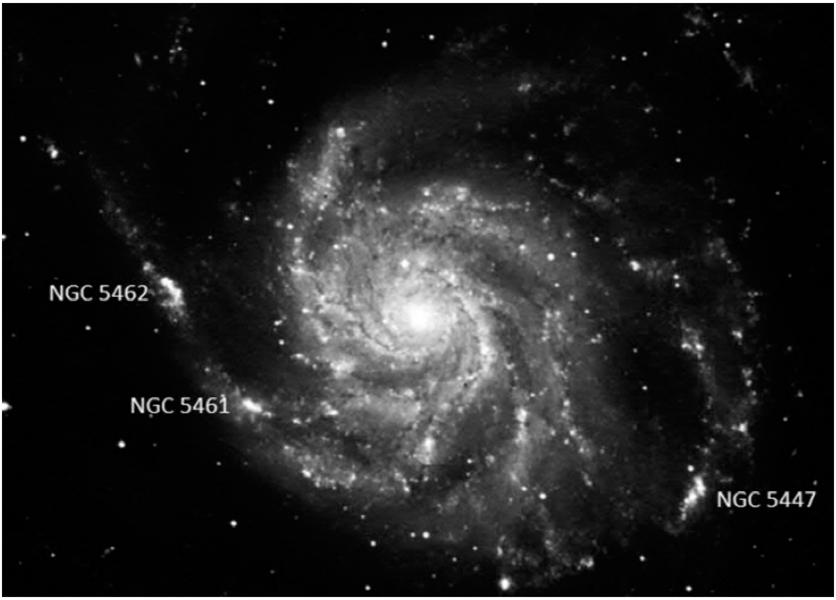


Figure 2-172: The large face-on galaxy M 101 in Ursa Major with three bright HII-regions, found by Herschel (image 20' × 20').

On the night of 14 April (sweep 923), Herschel found a double nebula in Ursa Major: NGC 4284 (III 798, 13.5 mag) and NGC 4290 (II 805, 12.0 mag), the latter is 4.6' east (following). Only 13.3' south of the pair is the 5.5 mag star 70 UMa; Herschel missed it, being just outside the field of view when the tube moved downwards. He first noticed NGC 4284. In looking at it, NGC 4290 entered the field. Curiously, he noted the reverse sequence, which is impossible: it would need the 'side motion', not available in the north. Moreover, he missed an object, located only 12' east of NGC 4290: M 40. The pair of stars would have been of interest: as the only Messier object that William has never seen. Caroline viewed M 40 on 7 August 1783 with the sweeper (Figure 1-53).

In sweep 928 (24 April), a round nebula in Draco was sketched, the 12.3 mag galaxy NGC 6338 (II 812).[742] On the 26th (sweep 929), William saw a "faint, very small, stellar" nebula in Canes Venatici. It was catalogued as II 815. Dreyer lists it as NGC 4987. Indeed, there is a 13.4 mag galaxy at the place, but this cannot be his nebula. The reason is due to his earlier observation, the discovery of NGC 4998 (III 819). This nebula was seen 26^s earlier. Thus,

Caroline correctly calculated for II 815 an AR that is 26^s greater than III 819. However, the AR of Dreyer's NGC 4987 is 58^s smaller! William must have swept backwards, which is impossible. Because II 815 is 1.4° more north, the sweep speed was pretty high to reach the new field. Taking the offsets in AR and PD, one lands at a place about 10' northeast of NGC 4987. Is there a nebula? Indeed: the 13.6 mag galaxy MCG 9-22-20, which is the very II 815. The latter and NGC 6338 are seen in Figure 2-173.

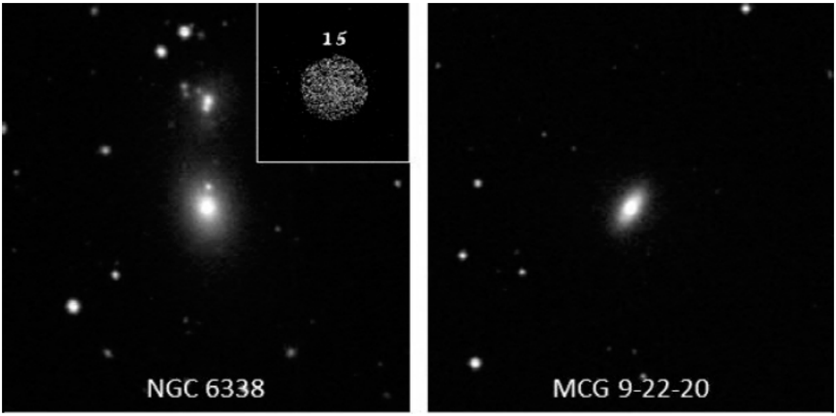


Figure 2-173: Left: NGC 6338 in Draco, found on 24 April 1789 (inset). Right: Herschel's nebula II 815 = MCG 9-22-10, found on 26 April 1789 in Canes Venatici and incorrectly catalogued by Dreyer as NGC 4987 (both images 5' × 5').

Sweep 932 on 18 July was already the last of 1789. What happened in the remaining months? Herschel was concerned with Saturn, using the 20-ft. Moreover, the 40-ft was completed and ready for regular observations.

On 27 August, a further trial sweep was made with the great reflector; the mirror had just been polished by a machine: "The speculum gives a pretty sharp image of the stars. The large ones are affected with a very small burr, or rather scattered light, owing to the remaining scratches in the Speculum." The attempt in Aquarius brought a nebula, though not a new one: NGC 7392 (II 702), discovered on 11 September 1787 (sweep 754). The trial sweep ended after 45 minutes.

Another one was made in the next night (28 August), now with a power of 189. It brought the first true discovery: NGC 7441, a 13.8 mag galaxy in Aquarius. The object was not catalogued for a simple reason: there was no reference star and thus a position was not determined. The night ended with Saturn and its moons.

In the next trial sweep on 11 September (breadth 1°), Herschel saw a nebula in the centre of the Pisces heptagon: NGC 7585. The 13.2 mag galaxy, already found on 20 September 1784 (II 236), was not registered. After the sweep, lasting only 20 minutes, Saturn was observed. All trial sweeps were made in the vicinity of the ringed planet. In total, only three non-stellar discoveries can be credited to the 40-ft (Table 2-47, Figure 2-174).

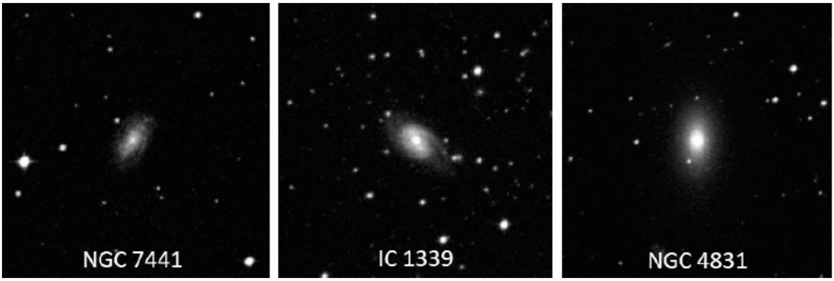


Figure 2-174: The three galaxies NGC 7441, IC 1339 and NGC 4831 were found by Herschel with the 40-ft (all images 5' × 5').

Object	Date	Sweep	V	Con	Remarks
NGC 7441	28 Aug. 1789	trial	13.8	Aqr	Stone 1886
IC 1339	29 Sep. 1791	ecliptic	13.2	Cap	Swift 1888
NGC 4831	9 Apr. 1793	ecliptic	12.5	Hya	J. Herschel 1836

Table 2-47: Three objects (all galaxies) were discovered with the 40-ft. Alas, Dreyer credited them to other observers.

The next trial sweeps, made on 16 & 17 September, were exclusively dedicated to Saturn. On the latter date, Herschel believed to have seen a 7th satellite, which was not the case. On the 24th, he wrote: "I viewed Saturn, but saw no other Satellite than what the 20 feet shewed. My brother Alexander, Mrs. Herschel [Mary] & another Lady saw it also. The Satellites (viz the 2nd, 3rd, 4th & 5th) were very bright." Actually, Herschel had discovered a

seventh satellite (Mimas) already on 8 September with the 20-ft; the 12.9 mag object was called “the new or 6th“. Like in the case of Enceladus, he again had trouble with the numbering (see section 2.6.2).

After the trial sweeps, being more or less Saturn observations, Herschel made his first ‘official’ sweep on 20 October, named ‘1 Sweep’ (see Table 2-56). Now the planet played no role. It started about 11:50 pm in Cetus, the breadth was 1°. He immediately saw a “considerably bright, extended” nebula at an elevation of 32°. Because 67 Cet (of Wollaston’s catalogue) was seen 17 minutes later, the position of the nebula could be determined. It is the 11.9 mag galaxy NGC 779. Herschel had found the object already on 22 November 1785 (I 101) in sweep 436 (Figure 2-175). His ‘1 sweep’ with the 40-ft lasted only 25 minutes.

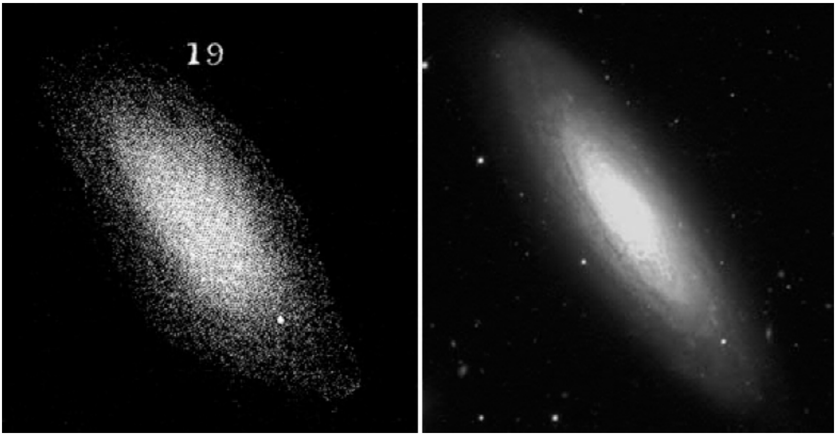


Figure 2-175: The 11.9 mag galaxy NGC 779 in Cetus was observed with the 40-ft on 20 October 1789. Herschel had found it already on 22 November 1785; a sketch was made.

On 2 December, ‘2 sweep’ was made; only 36 Cet was seen (the 6.6 mag star was taken from Wollaston’s catalogue). Obviously, sweeping with the 40-ft was a short and ineffective matter. Thus, it’s not surprising that it took about 1½ years until Herschel performed another one, named ‘3 sweep’ (see Table 2-56).

From the beginning of 1789 until the end of sweeping with the 20-ft on 18 July, 62 observing nights were used. This is only 19% of all

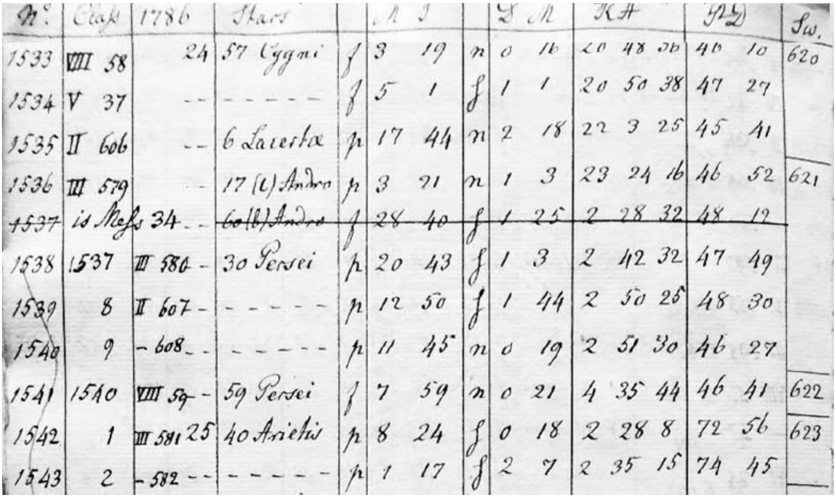
nights. In 81% of the time, planets were observed. This is a reversal of earlier years. In the future, sweeping was actually more reduced.

2.7.3. Herschel's second catalogue of nebulae and star clusters

19 October 1788 was a special day for the Herschels. In sweep 868, William discovered the open cluster NGC 7209 (VII 53) in Lacerta, which Caroline entered as object no. 2000 in her 'General catalogue'.[743] But, after considering the problems during the compilation of the first catalogue (see section 2.4.1), we may ask: How could she be sure that the critical number of 1000 new objects was actually reached?

Of course, Caroline could not. The large table is ordered by the time of discovery. Each object was assigned a 'General number', shown in the first column 'Nº.' (Figure 2-176). The other concern class designation, discovery date, reference star, relative position, absolute position (for 1790) and sweep number. However, corrections indicate that the 'General number' was occasionally changed, due to identities or errors, tracked down in the data. Such problems did not become obvious in the regular work, like recording sweeps, processing the data and copying new objects into the 'General catalogue'. But now, considering a publication, Caroline must check the data to get a clean product. She found 13 entries to be deleted. Three times a Messier object was the reason: M 34, M 51 and M 52. In the other cases, the entry was identified with a former one, bearing a number above 1000 (i.e. not belonging to the first catalogue).

The correction process can be traced in her table. The open cluster M 34 in Perseus is entry no. 1537, referring to sweep 621 (24 October 1786). The 'Original' record only speaks of a "coarse cluster of large stars of different sizes". After erasing, no. 1537 went to III 580 (NGC 1138), a galaxy in Perseus. Because this happened another 12 times, Caroline was forced to introduce a new column for the corrections; the former numbers were marked by a wavy line. This all means: no. 2000 was not reached on 19 October! The new qualifying date should be 3 December (sweep 889), when III 747 was found, an 11th mag galaxy in Camelopardalis.



N°	Class	1786	Stars		AR		D M	RA	PD	Sw.
1533	VIII 58	24	57 Cygni	f	3 19	n	0 16	20 48 36	40 10	620
1534	V 37	--	------	f	5 1	f	1 1	20 50 38	47 27	
1535	II 606	--	6 Lacertae	p	17 44	n	2 18	22 3 25	45 41	
1536	III 579	--	17 (ι) Andro	p	3 21	n	1 3	23 24 16	46 52	621
~~1537~~	is Mess 34	--	~~60 (β) Andro~~	~~f~~	~~28 40~~	~~f~~	~~1 25~~	~~2 28 32~~	~~48 19~~	
1538	1537	III 580 -	30 Persei	p	20 43	f	1 3	2 42 32	47 49	
1539	8	II 607 -	------	p	12 50	f	1 44	2 50 25	48 30	
1540	9	- 608 --	------	p	11 45	n	0 19	2 51 30	46 27	
1541	1540	VIII 59 -	59 Persei	f	7 59	n	0 21	4 35 44	46 41	622
1542	1	III 581 25	40 Arietis	p	8 24	f	0 18	2 28 8	72 56	623
1543	2	- 582 --	------	p	1 17	f	2 7	2 35 15	74 45	

Figure 2-176: Part of Caroline's 'General catalogue', showing corrections due to the unwanted object M 34 (see text).

After this revision, the catalogue of 1000 new nebulae and clusters could be compiled. Caroline sorted the large table by class to get the structure of the first catalogue. Again, 'General number' and coordinates (absolute positions) were omitted. Fortunately, we have the manuscript, sent to the *Royal Society*.[744] It is titled 'Catalogue of a 2nd thousand of New Nebulae etc.' and dated 1 May 1789. Obviously, the making took five months. The text starts with a 17-page introduction, which is exclusively due to William (though the whole text was written down by Caroline). It begins as follows:

By the continuation of a review of the heavens with my twenty-feet reflector, I am now furnished with a second thousand of new Nebulae. These curious objects, not only on account of their number, but also in consideration of their great consequence, as being no less than whole sidereal systems, we may hope, will in future engage the attention of Astronomers. With a view to induce them to undertake the necessary observations, I offer them the following catalogue, which, like my former one, of which it is a continuation, contains a short description of each nebula or cluster of stars, as well as its situation with respect to some known object. The form of this work, it will be seen, is exactly that of the former part, the classes and numbers being continued, and the same letters used to express, in the shortest way, as many essential features of

the objects as could possibly be crowded into so small a compass as that to which I thought it expedient to limit myself.

The remaining text concerns Herschel's method to evaluate the 'construction of the heavens' by counting stars in the field of view ('star gage').[745] The main part of the paper are the tables for the eight classes in the format of the first catalogue. Notes on 11 entries follow. Finally, there is a postscript about the discovery of a "fifth satellite of Saturn" (see section 2.6.2).

The manuscript of the second catalogue was read to the *Royal Society* on 11 June. Herschel's paper was the 20th (of 24), arranged for publication in volume 79 of the *Philosophical Transactions* for 1789. It appeared in the 'June issue' of the journal, which was delivered in late 1789 (Figure 2-177).[746]

XX. *Catalogue of a ſecond Thouſand of new Nebulæ and Cluſters of Stars; with a few introductory Remarks on the Conſtruction of the Heavens. By* William Herſchel, *L L. D. F. R. S.*

Read June 11, 1789.

BY the continuation of a review of the heavens with my twenty-feet reflector, I am now furniſhed with a ſecond thouſand of new Nebulæ.

Figure 2-177: Title page of Herschel's second catalogue of nebulae and star clusters.

What happened in the five months between the discovery of the true object no. 2000 and the closing date of Caroline's manuscript? Of course, sweeping! But any new object had to wait for publication in a future third catalogue. There were also re-observations of known ones. The total number for each object is given column 'Ob'. It ranges from 1 to 4 and concerns only objects of the second catalogue.[747] An analysis shows that 27 objects were observed again after the discovery of no. 2000 (III 747) in sweep 889. It

starts with V 44 (NGC 2403), found as no. 1994 in sweep 879, and seen a second time in sweep 889, shortly after III 747. The period ends – and this is the crucial date – on 26 April 1788 with Herschel's second view of II 744 (no. 1923) in sweep 929. This is the last observation, included in the catalogue. 163 objects were discovered between 3 December 1788 and 26 April 1789.

The analysis shows that the number of observations, given by Caroline, is incorrect for some objects. But this is minor problem. The more challenging one concerns the identity of entries. Though she has tracked down some cases, there are still more; they can be sorted in three categories (Table 2-48):

I. The object was found by William (Ia) or Caroline (Ib) prior to the sweep campaign; it should already appear in the first catalogue.
II. The object is already contained in the first catalogue.
III. The object appears twice in the second catalogue.

Cat	Obs	NGC	H	Con	Type	Date1	Sw1	Date2	Sw2	Identity
Ia	W	5195	I 186	CVn	Gx	12 May 1787	734	17 Sep. 1783		
Ia	W	14	II 591	Peg	Gx	18 Sep. 1786	590	24 Dec. 1783	62	
Ia	W	2264	V 27	Mon	OC	26 Dec. 1785	494	15 Feb. 1781		VIII 5
Ia	W	1980	V 31	Ori	EN	31 Jan. 1786	517	20 Sep. 1783		
Ia	W	869	VI 33	Per	OC	1 Nov. 1788	877	2 Aug. 1780		
Ia	W	884	VI 34	Per	OC	1 Nov. 1788	877	2 Aug. 1780		
Ia	W	2349	VII 27	Mon	OC	24 Feb. 1786	529	24 Feb. 1786	529	
Ia	W	752	VII 32	And	OC	21 Sep. 1786	599	24 Aug. 1783		
Ia	W	457	VII 42	Cas	OC	18 Oct. 1787	769	18 Aug. 1780		
Ia	W	2281	VIII 71	Aur	OC	4 Mar. 1788	813	6 Nov. 1782		
Ib	C	7789	VI 30	Cas	OC	18 Oct. 1787	769	30 Oct. 1783		
Ib	C	2311	VIII 60	Mon	OC	26 Nov. 1786	639	4 Mar. 1783		
Ib	C	6633	VIII 72	Oph	OC	30 Jun. 1788	850	31 Jun. 1783		
Ib	C	7380	VIII 77	Cep	OC	1 Nov. 1788	876	7 Aug. 1787		
Ib	C	225	VIII 78	Cas	OC	26 Nov. 1788	887	27 Sep. 1783		
II	W	217	II 480	Cet	Gx	28 Nov. 1785	479	24 Dec. 1783	62	
II	W	2872	II 546	Leo	Gx	3 Mar. 1786	534	15 Mar. 1784	172	II 57
II	W	2874	II 547	Leo	Gx	3 Mar. 1786	534	15 Mar. 1784	172	II 58
II	W	4474	II 629	Com	Gx	14 Jan. 1787	691	8 Apr. 1784	187	II 117
II	W	6514	IV 41	Sgr	EN	26 May 1786	566	12 Jun. 1784	236	V 10, V 11, V 12 = M 20
II	W	206	V 36	And	GxP	17 Oct. 1786	613	5 Oct. 1784	282	
II	W	2254	VII 22	Mon	OC	28 Dec. 1785	496	26 Dec. 1783	67	no. 22
III	W	4460	I 212	CVn	Gx	10 Apr. 1788	830	27 Apr. 1788	833	II 750
III	W	3611	II 521	Leo	Gx	27 Jan. 1786	514	15 Apr. 1786	552	II 626
III	W	4281	II 571	Vir	Gx	17 Apr. 1786	553	23 Apr. 1786	556	II 573
III	W	259	II 621	Cet	Gx	13 Dec. 1786	646	13 Dec. 1786	646	II 703

Table 2-48: Identities in Herschel's second catalogue (objects within a category are sorted by class).

2.7.4. Summary of 1788–89

Table 2-49 gives the statistical data of the sweeps made in 1788 and 1789. The first year starts with no. 796 on 7 January and ends with no. 903 on 31 December; the second starts with no. 904 on 20 January and ends with no. 933 on 18 July.

Category	1788	Remarks	1789	Remarks
number of nights	69		14	
longest continuous period (days)	4	28 April – 1 May	-	
longest break (days)	29	9 June – 8 July (marriage)	65	14 May – 18 July (2nd catalogue)
number of sweeps	108		29	
sweeps per night (maximum)	9	3 Feb.	8	22 Feb.
mean night (hours)	2.4		3.0	
longest night (hours)	11.6	3 Feb. (observing 6.9 hours)	6.3	24 Apr. (observing 3.2 hours)
lowest elevation (°)	19	2 Mar.	13	24 Feb.
lowest PD (°)	13		14	
observed objects	296		212	
objects per night (mean)	4.3		15.1	
sweeps without objects	36		63	
new objects (all)	166		152	
uncatalogued objects	2	Table 5-5	1	Table 5-5
re-observed objects	130		60	
most productive night	3 Feb.	37 objects	14 Apr.	37 objects
new objects: first	-	NGC 2775 (Gx Cnc)	-	NGC 2304 (OC Gem)
last	-	NGC 3334 (Gx LMi)	-	NGC 7441 (Gx Aqr); Figure 2-174
brightest (mag)	4.6	NGC 6633 (OC Oph), record	9.8	M 109 Gx UMa)
faintest (mag)	14.2	NGC 6241 (Gx Her)	15.5	NGC 4879 (Gx Vir)
smallest (")	33	NGC 6742 (PN Dra)	24	NGC 4549 (Gx UMa)
multiple	4	4 pairs	9	9 pairs
Messier objects:	10		8	
first observation	2		3	
first with 20-ft	3		4	
new double stars	9		1	
new garnet stars	1		-	
star gages	12		-	
vacant places	1		-	

Table 2-49: Sweep statistics for 1788 and 1789.

1788 saw William's marriage with Mary Pitt, half a year before his 50th birthday. Caroline's discovered her second comet. The 40-ft was used for trial sweeps, though with no great success. The 2000th object was observed in a sweep; the signal for William to compile a second catalogue. The first non-Flamsteed reference star was used, taken for a draft of Wollaston's catalogue. In 1789 the second catalogue was read to the *Royal Society*. A galaxy was found with the 40-ft near Saturn. The new moons Mimas and Enceladus were observed. Two regular sweeps were made with the giant reflector, but nothing was found.

2.8. Observations in 1790–91

2.8.1. Caroline's 3^{rd} and 4^{th} comet, William's 'star with an atmosphere'

The year 1790 started with the discovery of Caroline's 3^{rd} comet on 7 January.[748] While using the small sweeper, she noted at 8:20 pm (Figure 2-178): "I see an object like a star with a burr all around, but a very strong fogg prevents all further observations. I hope to find the place again by the 4 stars delineated." The 5.6 mag object was located in Vulpecula at an altitude of 21° above the western horizon. After two cloudy days "we found the comet of the 7^{th} again." William viewed it with the 7-ft reflector.[749]

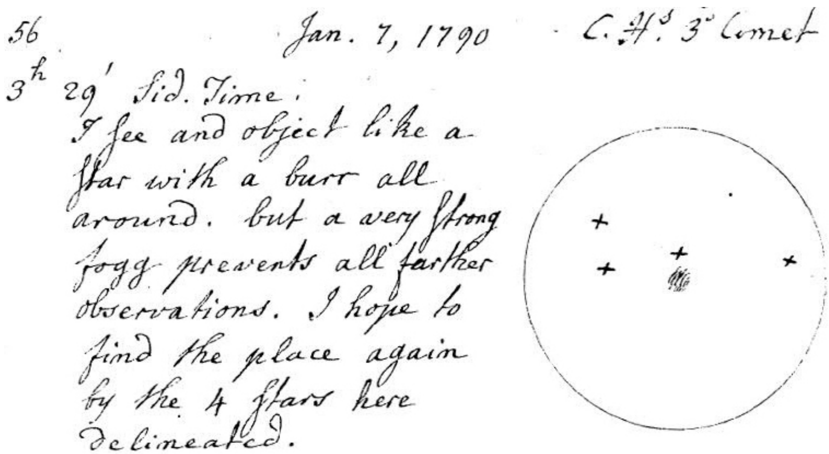


Figure 2-178: Discovery record of Caroline's 3^{rd} comet on 7 January 1790.

On 18 January another comet was observed by Herschel, found on the 9^{th} by Méchain. At about 8 pm, the 6^{th} mag object was 25° above the southern horizon in Cetus. He showed it to two guests, "Dr. Lind and Mr. Cavallo".[750] The night also brought observations of Mars and Jupiter with the 40-ft.

Uranus was observed on 17 February with the 20-ft. At about 10 pm it was located only 2.2° southeast of Presaepe (M 44) in Cancer.[751] Then the first sweep (933) of the year was made,

starting at 11:30 pm. Herschel saw “a red star” in Antlia, only 6° above the horizon. The 5.8 mag orange star (HR 3932) was later identified as “26 (π) Antlia penumatica of Bode’s Cat.” Then a nebula in Hydra entered the field of view: “Pretty bright, extended from about 70° np to sf, about 6 or 7' long near 4' broad, very gradually brighter middle, within a parallelogram of stars.” This is the galaxy NGC 3621 (I 241); the 9.7 mag bright object was only 7° above the horizon. It is among Herschel’s objects with the lowest declination (see Table 2-51 and Figure 2-181).

4 March (sweep 934) brought a nice, but very small object in Puppis: NGC 2440 (IV 64): “A beautiful planetary Nebula of a considerable degree of brightness; but not very well defined. About 12 or 15" diameter.” Another planetary followed the next night (sweep 935) in Monoceros: “A pretty considerable star 9 or 10m, visibly affected with very faint nebulosity, of very little extend all around. 300 shewed the same, but gave a little more extent to the nebulosity.” The object (IV 65) was included in Herschel paper on ‘nebulous stars’ (1791). It is NGC 2346 (11.6 mag); the central star has a magnitude of 11.2.

Sweeps 945–958 (17 March to 17 September) were again made in the north, above the pole. In the first “A meteor passed through the field, of the brightness of a star of 2nd magnitude. While I swept up and down, the remainder of its train was visible when I came to its altitude.” 12 minutes later, Herschel saw a nebula in Lynx, catalogued as III 830. However, he did not notice that this is a very close double galaxy: NGC 2474/75 (distance 22"). The contact pair of elliptical galaxies has a common brightness of 13.1 mag.[752] Sweep 954 on 20 March brought a star of “deep garnet colour” in Draco (U^{939}); the 6.3 mag object is the variable RY Dra (see Table 2-11).

The sweep period was often interrupted; only two nights were used between 1 April and 7 September. In the free time, Caroline scanned the skies with the small sweeper. And again, she provided a highlight: her 4th comet, found on 17 April at about 2:45 am, shortly after inspecting the dark part of the Moon (Figure 2-179).[753] The 7th mag object was in Andromeda, at the border to Pegasus, 31° above the north-eastern horizon. On 3 May, William

noted:754 “I saw the comet my sister discovered the 14th [sic] of April while I was on a little journey in Yorkshire. It was but small, but considerably bright in the small sweeper. I did not see it in another instrument, the weather being very indifferent & the object low.”

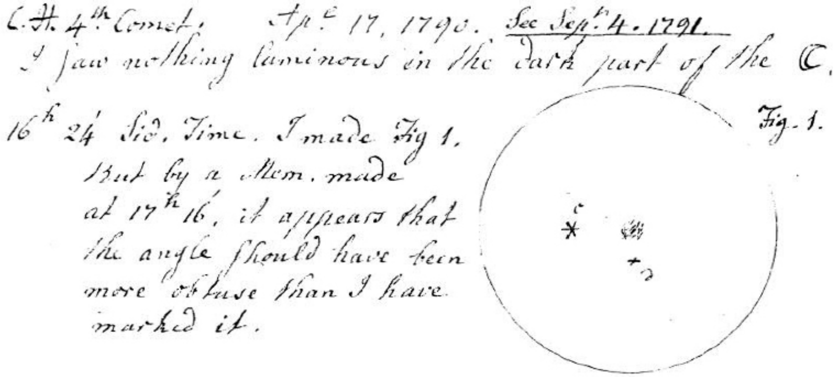


Figure 2-179: Discovery record of Caroline’s 4th comet on 17 April 1790.

On 2 May, Caroline noted about the comet: “Its light appeared more bright, than that of the nebula in the girdle of Andromeda [M 31], the situation of both objects was very low, and the weather cloudy and hazy. The comet precedes the nebula about 1 ½ of my fields of view, and is a little more than 1 field north of it.” She added “Small Sweeper”.

This is important, because for her comet observation of 13 May we read “Large Sweeper”. The instrument was a 9.6-inch Newtonian with 5 feet 3 inches focal length; the standard field of view was 1.5° (Figure 1-40).755 Caroline added: “The Speculum is so much tarnished, that I could not be very nice in noticing the time; on account of the obscure appearance the come made in this instrument, in the small sweeper it appeared very bright.” This is confirmed at the end of her second *Book of Observations*:756 “May 13, 1790. Mem. Large Sweeper. Mirror much tarnished (The Instrument was fixed on the Top of the house and the Mirror had no case sufficiently tight for remaining always in the Tube.)” And on the 17th, Caroline wrote that the Moon was observed “with the new sweeper, double eye-piece [2 lenses]”.757 This implies that the large

sweeper was probably built by William in winter 1789/90. Curiously, these dates are in conflict with a remark in her letter to Lalande of 12 September:[758] "An excellent Newtonian sweeper, of 5 feet focal length is nearly completed; which being mounted at the top the house [cottage] will always be in readiness for observing, whenever my attendance on the 40 or 20 foot telescopes is not required." Also confusing is Caroline's memorandum on the first page of her *Journal 4*, dated 19 July 1791:[759] "But as I intend to keep a regular Journal, when my new sweeper is finished, I will begin, by way of practice, to keep some sort of memorandum." This only means that, from this date on, observations with the large sweeper were recorded in a separate document; it ended on 22 January 1795 (*Journal 2* was still used until 1797). There is no doubt that the large sweeper was operational on 13 May 1790. Caroline followed her 4th comet until 10 June.

On 19 March (sweep 953), William found the 10.2 mag galaxy NGC 5322 (I 256) in Ursa Major. It was sketched (Figure 2-180), being an example of "nebulae which are suddenly much brighter in the middle", treated in his publication of 1811 (see section 4.2.1).

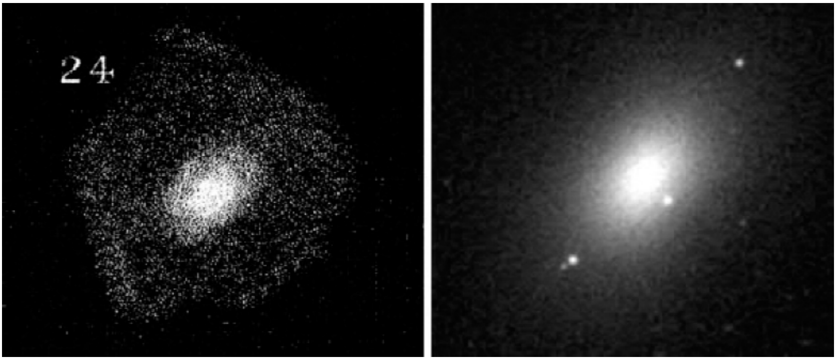


Figure 2-180: The 10.2 mag galaxy NGC 5322 in Ursa Major was discovered on 19 March 1790.

On 5 June, Herschel had three guests: Abbe Rochow, Count de Brühl (Hans Moritz v. Brühl) and Alexander Aubert. On 8 August, Abbe Ungeschick visited Slough.[760] In September, Herschel observed Saturn with the 20-ft.

On 1 October (sweep 962), Herschel inspected Equuleus, nothing

was found. The small constellation was visited again on the 10th (sweep 973), now offering a nebula. This is the 13.1 mag galaxy NGC 7046 (III 858), his only find in Equuleus (see Figure 5-20).[761]

On the 3 October (sweep 964), Herschel revisited on old friend, NGC 7662 (IV 18) in Andromeda: "My planetary nebula. A very beautiful object, with a very small star following; giving one the idea of a large Planet with a very small Satellite." This idea was first expressed by Jean Dominique Cassini, when he saw NGC 7662 with the 20-ft on 27 November 1787. It was later taken over by John, whose examples were the planetary nebulae NGC 6818 in Sagittarius ("exactly like a planet and two satellites"), NGC 6905 in Delphinus ("it has four small stars near it like satellites") and, of course, NGC 7662, which contains a double star. He expected an 'orbital motion', reminding himself that "these satellites of planetary nebulae ought to be especially attended to". Some later astronomers took the matter seriously.[762]

In sweep 971 (9 October), Herschel tried a new eye-piece with magnification 360×. Table 2-50 gives an overview about the collection, used for sweeping with the 18.7-inch reflector. His target was the galaxy NGC 7760 (II 854) in Pegasus: "Two very small close stars with seeming nebulosity between them. 360 confirmed it nearly." Actually, the 13.4 mag galaxy is centrally superimposed by a pair of 14th mag stars, only 7" apart. 12 minutes later, he found a double galaxy: "Two, extremely faint, stellar, between 1 of each other, from 30° sp to nf." With a distance of 50", it is one of his closest pairs: NGC 7805/06 (III 855/56) in Pegasus, shining at 13.3 and 13.5 mag, respectively (see Table 2-28).

Eye-piece	No. 1	No. 4	No. 5	-	-
focal length (in)	1.53	1.00	0.80	0.75	0.67
magnification	157	240	300	320	360
field of view (')	15	10	8	7	6

Table 2-50: Herschel's eye-pieces with known data, used for sweeping with the 18.7-inch reflector. 'No. 1' was the standard; for the last two, no designation is given in the documents.[763]

In the same night (sweep 972), Herschel swung down to Fornax, to discover objects with low declination. The first was the large galaxy

NGC 1097. The 9.5 mag barred spiral was catalogued as V 48: "Very bright, extended, from np to sf about 8' long, a very bright nucleus, confined to a small part about 1' diameter." He has mainly seen the bright bar; the spiral arms of the face-on galaxy were too faint for him. The object was only 7.4° above the horizon. Even lower (6.7°) was the second: the 10.4 mag galaxy NGC 1344 (I 257). The minimum (6.6°) was reached with the 13.1. mag galaxy NGC 1366 (III 857).

It is phenomenal that Herschel perceived the faint object so near to the horizon. Table 2-51 and Figure 2-181 show all non-stellar objects, discovered below -30° declination. For a tube elevation below 8°, the front gallery was not used. Caroline wrote:[764] "Without Gallery, standing or sitting on proper steps on the Ground." Between 8° and 15°, Herschel was sitting on a stool upon the gallery.

Decl	E (°)	NGC	H	Sw	Date	Con	V	Type
-31 52	6.6	1366	III 857	972	9 Oct. 1790	For	11.1	edge-on lenticular galaxy
-31 51	6.7	6569	II 201	237	13 Jul. 1784	Sgr	8.4	globular cluster, concentration class VIII
-31 46	6.7	1344	I 257	972	9 Oct. 1790	For	10.4	elliptical galaxy
-31 43	6.8	3621	I 241	933	17 Feb. 1790	Hya	9.7	elongated spiral galaxy
-31 07	7.4	1097	V 48	972	9 Oct. 1790	For	9.5	face-on barred spiral

Table 2-51: Herschel objects with the lowest declinations (1800), found in the sweeps (E = tube elevation); three were seen on 9 October 1790 in Fornax.

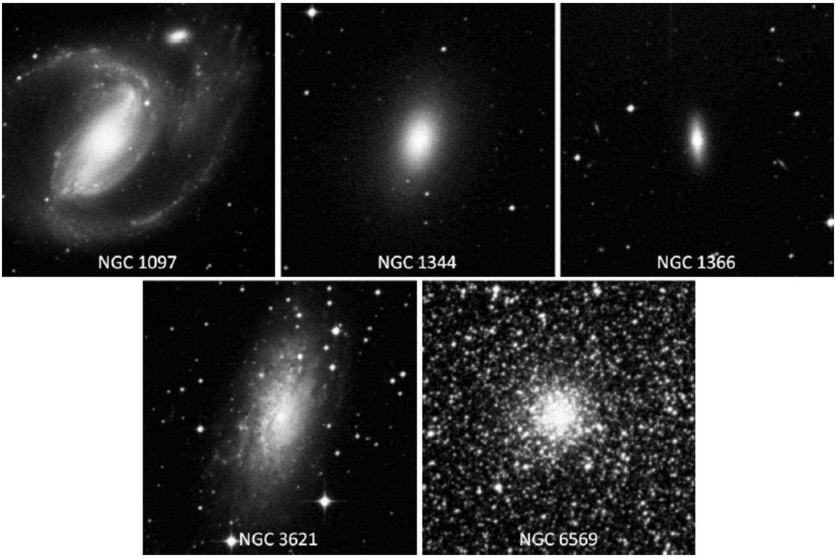


Figure 2-181: The southern objects of Table 2-51. The companion of NGC 1097 is NGC 1097A (13.1 mag), not seen by Herschel (all images 7.5' × 7.5').

On 22 October 1790, Herschel watched a total lunar eclipse (Table 2-54).[765] The phenomenon was viewed with the 20-ft at 360×. A brief report appeared in 1792, titled 'Remarkable Phenomena in an Eclipse of the Moon'.[766] Herschel wrote: "In several parts of it I perceived many bright, red, luminous points. Most of them were small and round."

Herschel had his highlight of the year on 13 November. Sweep 980 started a few minutes before midnight in Perseus. About half an hour later, he saw an exceptional 9.5 mag star in northern Taurus:

A most singular phenomenon. A star about 8m, with a faint luminous atmosphere of a circular form, of about 3' diameter. The star is perfectly in the center, and the atmosphere is so diluted, faint and equal throughout that there can be no surmise of its consisting of stars; nor can be there no doubt of the evident connection between the atmosphere and the star. Another star not much less in brightness and in the same field with the above, was perfectly free from any such appearance.

Herschel studied the object for some minutes by the ‘side motion’. It is the 10.9 mag planetary nebula NGC 1514 (IV 69); Figure 2-182. This observation changed his view about the nature of unresolvable nebulae. He now believed that they consist of luminous matter – and are by no means remote clusters of stars, as assumed before. Obviously, true nebulosity existed! This observation and others, inspired him to write a paper on ‘nebulous stars’, presenting his new theory. Actually, it was a rebirth of his early idea about the nature of the Orion Nebula.

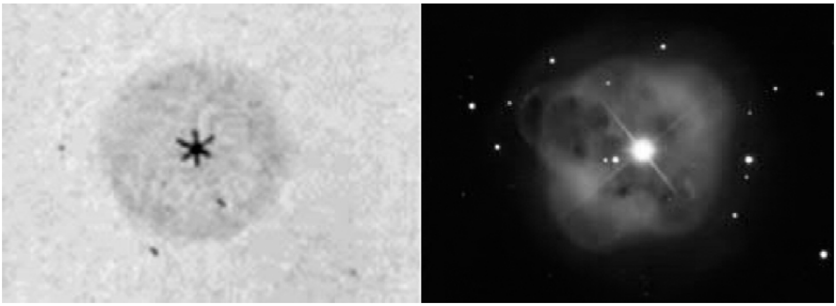


Figure 2-182: ‘A most singular phenomenon’: the 10.9 mag planetary nebula NGC 1514 in Taurus, discovered on 13 November 1790. The central star dominates a round area of nebulous matter; this led to the term ‘star with an atmosphere’.

Sweep 980, lasting about 2.5 hours, brought only one other non-stellar object: the reflection nebula NGC 1985 (III 865) in Auriga. Herschel confirmed the small object with 300×. It is only 3.5° away from the (imaginary) Galactic Anti-Centre.

On the 28 December (sweep 989), William saw “a star of about 9m of a very deep garnet colour”; it was catalogued as U^{976}. This is the variable V466 Per, shining at 8th mag (see Table 2-11). In the same night (sweep 990), when observing in Lynx, he discovered the “very faint, very small” nebula III 875. Then another nebula was seen, 2.9' northeast. Caroline identified it with II 735, discovered in sweep 815 on 9 March 1788. This is wrong. Actually, the first nebula of sweep 990 (III 875) is identical with the object of sweep 815 (II 735). Dreyer has noticed the identity, cataloguing the 12.5 mag galaxy as NGC 2329 = II 735 = III 875. But what is the companion? This is the 13.6 mag galaxy UGC 3696 – another non-

NGC/IC find by Herschel (see Table 5-5).

2.8.2. Herschel's 'nebulous stars' and planetary nebulae

The discovery of a 'star with atmosphere', NGC 1514 (IV 69), led Herschel to write a paper on 'nebulous stars' in general. Over the years, he had found a number of such objects. Many of them were put in class IV, 'planetary nebulae'. Actually, some are physical planetaries with a visible central star. The manuscript was finished on 1 January read to the *Royal Society* on 10 February. The paper appeared under the title 'On Nebulous Stars, properly so called' in volume 81 of the *Philosophical Transaction*.[767] In the introduction, Herschel wrote:

IN one of my late examinations of a space in the heavens, which I had not reviewed before, I discovered a star of about the 8th magnitude, surrounded with a faintly luminous atmosphere, of a considerable extent [NGC 1514]. The phenomenon was so striking that I could not help reflecting upon the circumstances that attended it, which appeared to me to be of a very instructive nature, and such as may lead to inferences which will throw a considerable light on some points relating to the construction of the heavens. Cloudy or nebulous stars have been mentioned by several astronomers; but this name ought not to be applied to the objects which they have pointed out as such; for, on examination, they proved to be either mere clusters of stars, plainly to be distinguished with my large instruments, or such nebulous appearances as might be reasonably supposed to be occasioned by a multitude of stars at a vast distance.

The text starts with describing various types of nebulae, which could be resolved into stars; primary examples are globular clusters, mainly listed in class VI ('very compressed and rich clusters of stars'). However, many resisted the resolution even with high power, thus landing in class I, II or III (depending on brightness). Herschel searched for the missing link: an object that connects the opposite forms 'star' and 'nebulosity'. Although some examples of 'nebulous stars' were found in the sweeps, the ultimate was IV 69 (NGC 1514) in Taurus. He wrote: "Our judgement, I may venture to

say, will be, that *the nebulosity about the star is not of a starry nature*."

H	NGC	Sw	Date	Ob	Con	Type	V	CS	Remarks
IV 19	2170	296	16 Oct. 1784	3	Mon	RN		10.6	listed twice; Figure 2-67
IV 20	2185	296	16 Oct. 1784	3	Mon	RN		11.6	Figure 2-67
IV 19	2170	528	23 Feb. 1786	3	Mon	RN		10.6	listed twice; Figure 2-67
IV 24	2023	352	6 Jan. 1785	1	Ori	EN+RN		7.9	
IV 25	2327	363	31 Jan. 1785	2	CMa	RN		11.2	
IV 33	1999	458	4 May 1785	4	Ori	EN+RN		10.9	sketch; Figure 2-108
IV 36	2071	506	1 Jan. 1786	3	Ori	RN		10.0	
IV 38	2182	529	24 Feb. 1786	2	Mon	RN		9.3	Figure 2-67
IV 44	-	640	28. Feb. 1786	1	Mon	RN		9.3	vdB 68; Figure 2-67
IV 45	2392	694	17 Jan. 1787	3	Gem	PN	9.1	10.5	Eskimo Nebula; Figure 2-140
IV 52	7635	773	3 Nov. 1787	2	Cas	EN	10.0	8.7	Bubble Nebula
IV 58	40	886	25 Nov. 1788	1	Cep	PN	12.3	10.6	
IV 57	6301	746	11 Jun. 1787	2	Her	Gx	13.4	-	superimposed star 13.9 mag
IV 59	3658	915	23 Mar. 1789	1	UMa	Gx	12.2	-	centre 14.4 mag
IV 62	3982	920	14 Apr. 1789	1	UMa	Gx	11.0	-	centre 14.6 mag
IV 65	2346	935	5 Mar. 1790	1	Mon	PN	11.6	11.2	
IV 68	2950	952	19 Mar. 1790	1	UMa	Gx	10.9	-	centre 12.4 mag
IV 69	1514	980	13 Nov. 1790	1	Tau	PN	10.9	9.4	sketch; Figure 2-182

Table 2-52: Herschel's collection of 'nebulous stars' in the paper of 1791 (his order is nearly chronological); Ob = number of observations, CS = magnitude of the central star; for galaxies the brightness of the centre is given.

Looking at Table 2-52, it is interesting that all objects are in class IV, 'planetary nebulae'. However, there are only three physical planetaries (PN) in the list. Most objects are reflection nebulae, where a star illuminates the surrounding dust clouds. In case of an emission nebula, a hot star excites the surrounding gas – mainly hydrogen, oxygen or nitrogen – to emit light in specific wavelengths (discrete spectrum). For reflection nebulae (RN), a magnitude cannot be given. The galaxies have a compact nucleus, with the exception of NGC 6301, where a star is superimposed, 16" southeast of the centre.

Most of the 'nebulous stars', listed in the table, were catalogued as 'planetary nebula' (class IV). However, only half of Herschel's class IV objects are actually physical planetaries in the modern sense. Table 2-53 shows all 34 PN, discovered by Herschel. The first, NGC 7009 (IV 1), was already seen in the star reviews with the 7-ft. It was observed 22 times (sweeps, later reviews with various

instruments). Another showpiece was NGC 7662 (IV 18) in Andromeda. 14 objects appear not in class IV: two are in I ('bright nebulae'), five in II ('faint nebulae'), five in III ('very faint nebulae'), one in V ('large nebulae') and one even in VI ('nebula or cluster of very close and faint stars').

GN	H	NGC	Sw	Date	Con	V	F	Dir	Loc	N	Remarks
5	IV 1	7009		7 Sep. 1782	Aqr	8.0	N		D	22	Saturn Nebula, 6.2-in
422	IV 11	6369	222	21 May 1784	Oph	11.4	N	S	D	2	
458	IV 13	6894	239	17 Jul. 1784	Cyg	12.3	N	S	D	4	
463	IV 14	6772	242	21 Jul. 1784	Aql	12.7	N	S	D	2	
465	II 204	6629	245	7 Aug. 1784	Sgr	11.3	N	S	D	1	
541	IV 16	6905	275	16 Sep. 1784	Del	11.1	N	S	D	2	Blue Flash Nebula
571	IV 18	7662	283	6 Oct. 1784	And	8.3	N	E	D	10	Blue Snowball; eastern sweeps
732	IV 26	1535	364	1 Feb. 1785	Eri	9.6	N	S	D	4	
746	IV 27	3242	368	7 Feb. 1785	Hya	7.7	N	S	D	4	Ghost of Jupiter
752	I 65	4361	368	7 Feb. 1785	Crv	10.9	N	S	D	1	CS 13.3 mag seen?
805	II 316	2371	385	12 Mar. 1785	Gem	11.2	N	S	D	2	
806	II 317	2372	385	12 Mar. 1785	Gem	11.2	N	S	D	2	
GN	H	NGC	Sw	Date	Con	V	F	Dir	Loc	N	Remarks
1187	V 25	246	478	27 Nov. 1785	Cet	10.9	N	S	C	1	
1237	IV 34	2022	496	28 Dec. 1785	Ori	11.6	N	S	C	2	
1263	IV 35	2610	503	31 Dec. 1785	Hya	12.7	N	S	C	1	
1337	IV 37	6543	523	15 Feb. 1786	Dra	8.1	N	N	C	1	Cat Eye Nebula, CS 11.4 mag
1378	IV 39	2438	540	19 Mar. 1786	Pup	10.8	N	S	C	2	
1471	II 586	6445	569	28 May 1786	Sgr	11.2	N	S	S	1	
1612	IV 45	2392	694	17 Jan. 1787	Gem	9.1	F	S	S	3	Eskimo Nebula, CS 10.5 mag
1676	III 637	6058	718	18 Mar. 1787	Her	12.9	F	S	S	1	
1804	IV 51	6818	749	8 Aug. 1787	Sgr	9.3	F	S	S	3	Little Gem
1812	I 192	7008	765	14 Oct. 1787	Cyg	10.7	F	N	S	3	CS 12.3 mag
1819	II 705	7354	773	3 Nov. 1787	Cep	12.2	F	N	S	1	
1831	IV 53	1501	774	3 Nov. 1787	Cam	11.5	F	N	S	2	
1833	III 696	7139	775	5 Nov. 1787	Cep	13.3	F	N	S	4	
1975	III 742	6742	849	8 Jul. 1788	Dra	13.4	F	S	S	1	
1977	III 743	6781	850	30 Jul. 1788	Aql	11.4	F	S	S	1	
1997	IV 58	40	886	25 Nov. 1788	Cep	12.3	F	N	S	1	CS 10.6 mag
2166	IV 64	2440	934	4 Mar. 1790	Pup	9.4	F	S	S	2	
2168	IV 65	2346	935	5 Mar. 1790	Mon	11.6	F	S	S	1	CS 11.2 mag
2268	IV 69	1514	980	13 Nov. 1790	Tau	10.9	F	S	S	1	CS 9.4 mag
2333	VI 38	6804	1018	25 Aug. 1791	Aql	12.0	F	S	S	1	
2412	IV 73	6826	1049	6 Sep. 1793	Cyg	8.8	F	S	S	1	Blinking Planetary, CS 10.4 mag
2421	III 936	7076	1062	15 Oct. 1794	Cep	13.5	F	N	S	1	

Table 2-53: Herschel discovered 34 physical planetary nebulae (PN). They are ordered by Caroline's 'General number' (GN), which refers to the discovery date (and sweep). The first object was found with the 6.2-in, all other with the 18.7-in. F = focus (Newtonian, front-view), Dir = south/north meridian (S, N) or east (E); Loc = Datchet (D), Clay Hall (C), Slough (S); N = number of observations. In a few cases, the central star (CS) was seen.

2.8.3. Caroline's 'large sweeper' and the 5th comet

In the first three months of 1791, Herschel observed Uranus with the 20-ft. On 1 March, Stephen George Demainbray visited Slough to see Uranus in the 20-ft. He was the son of the King's astronomer at Kew Gardens Observatory, Stephen Charles Demainbray, and became his successor in 1782. On 11 March, "The King of Polands brother saw many objects".[768]

Only three sweeps were made until 7 March. On that night (sweep 998), Herschel discovered a close double nebula in Hydra, noting "two, within a minute or two of each other". This is NGC 4105/06 (II 865/66); the distance between the 10.7 and 11.4 mag galaxies is 1.3'.

In the night of 2 April, the 1000th sweep was made. The telescope was turned to the north, above the pole. Two galaxies in Ursa Major were found: NGC 2805 (III 878, 11.0 mag) and NGC 2880 (I 260, 11.5 mag). Curiously the former, though the brighter one, was seen "very faint" and the latter "very bright". The telescope orientation was kept until sweep 1005.

Sweep 1001 (in the same night) brought a severe problem, originating from sweep 921 on 14 April 1789. It concerns the identification of non-stellar objects, seen for a short time only. In the northern sweep 921, Herschel had discovered four nebulae in Ursa Major, numbered and catalogued as GN 2079 (II 794), 2080 (III 778), 2081 (II 795) and 2082 (II 796). The reference star was Alioth (ε UMa). The positions are good and he, undoubtedly, saw the galaxies NGC 4644 (13.9 mag), NGC 4669 (13.2 mag), NGC 4674 (14.3 mag) and NGC 4686 (12.6 mg), respectively. They form a 1° long chain from northeast to southwest, located 1.8° southeast of the 1.8 mag star in the drawbar. Caroline plotted the nebulae in her 'Register of sweeps according to the time of observation' (Figure 2-183).[769]

Figure 2-183: The chain of four nebulae, discovered on 14 April 1789 (sweep 921) near Alioth in Ursa Major and plotted by Caroline in the 'Register of Sweeps' by their 'General number'.

Curiously, in sweep 1001 (2 April 1791), four nebulae in a chain were observed in the same region; the reference star was 73 UMa, 2.5° northeast. Being such a characteristic ensemble, Caroline had no doubt that these are the objects, already seen in sweep 921. Thus, they were recorded with their former numbers and designations in the record of sweep 1001. However, she noticed that the newly determined positions are all shifted towards the southeast (along the chain) by about 15'. In the *Zone Catalogue*, she explained the issue: "The difference in PD between the 1st & 2nd observation of 2079 […] is owing to the PD line not having been much used when the four sweep of April 2 and 3, 1791 were made." Obviously, Caroline assumed that the deviation had a technical reason.

We now know that all positions are correct, but the chain actually contains six galaxies (Figure 2-184). Thus, William has seen new members in the second observation: NGC 4646 (13.4 mag) and NGC 4695 (13.5 mag). Since the siblings could not resolve the case, it was now up to John, who first noticed that there is an additional object:770 II 794 = GN 2079, a double nebula, which was split into II 794,1 (GC 3177 = NGC 4644) and II 794,2 (GC 3179 = NGC 4646). However, he still thought that the different reference stars, used in the two sweeps, caused the problem. This is incorrect.

Dreyer commented the case in the NGC, repeating John's argument. In the *Scientific Papers*, he wrote a longer note about the issue, but again, the case was not sufficiently cleared. This is understandable. The former astronomers had no sky images, all conclusions must be drawn from the recorded data – more or less searching in the fog. Considering this, the number of errors is remarkably small. A modern analysis revealed the following identities (sweep number in brackets):

GN 2079 (921) = NGC 4644

GN 2080 (921) = NGC 4669

GN 2082 (921) = GN 2081 (1001) = NGC 4686

GN 2079 (1001) = NGC 4646

GN 2081 (921) = GN 2080 (1001) = NGC 4675

GN 2082 (1001) = NGC 4695

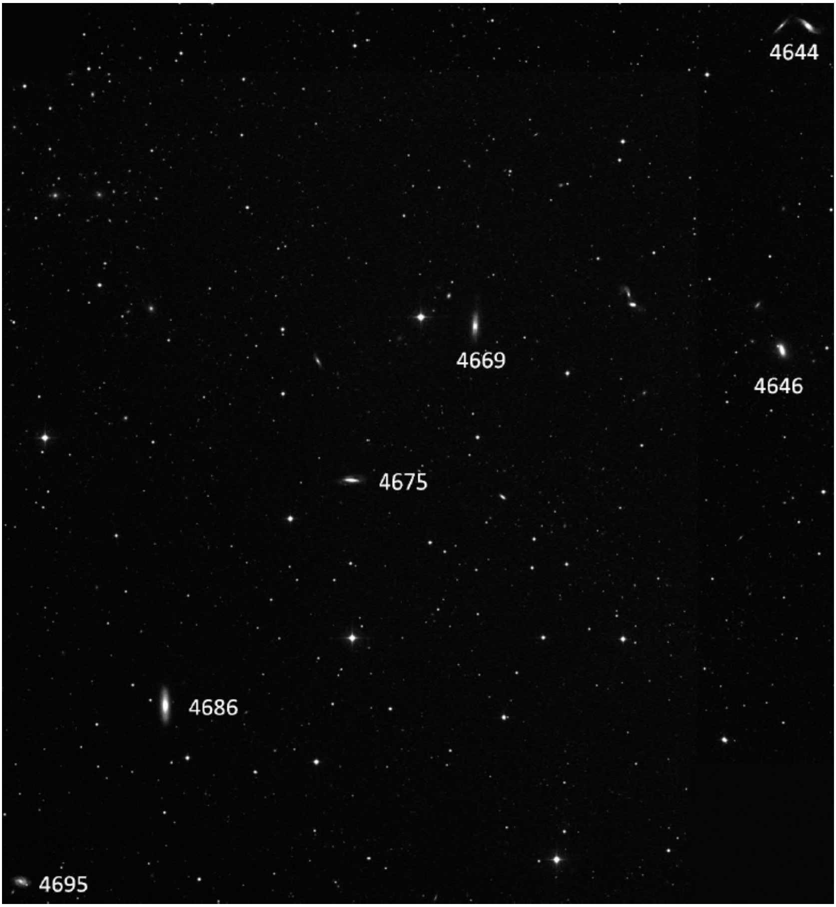


Figure 2-184: Six NGC galaxies near Alioth in Ursa Major, almost oriented in a 1° long chain. They were found by Herschel on 14 April 1789 and 2 April 1791. The first member (NGC 4644) is a double system.

On 3 April, Herschel watched his first solar eclipse, though only a partial one: “The edge of the Moon & its mountains are very well defined, and I ca see no difference in sharpness between the limb of the Moon and that of the Sun.” In total, he has seen six solar/lunar eclipses and two Mercury transits (Table 2-54). Unfortunately, Herschel never experienced a total solar eclipse (there was none in England at the time).

Phenomenon	Date	Remarks

total lunar eclipse	24 Feb. 1766	Leo, naked eye, 7 am, Kirby Hill
Mercury transit	4 May 1786	early morning, 7-ft
total lunar eclipse	22 Oct. 1790	Aries, 20-ft, power 360
partial solar eclipse	3 Apr. 1791	noon, 50%
partial solar eclipse	5 Sep. 1793	noon, 71%, 7-ft
Mercury transit	9 Nov. 1802	morning, 7-ft
partial solar eclipse	11 Feb. 1804	late forenoon, 65%, 7-ft, 10-ft
partial solar eclipse	16 Jun. 1806	late afternoon, 17%

Table 2-54: Phenomena concerning Moon and Sun; all observed at Slough, except the first.

In the following night (sweep 1004), Herschel discovered a spectacular pair of edge-on galaxies in Ursa Major, showing different orientations: “Two. The 1st faint, small, irregularly formed. The 2nd faint, pretty large extended.” This is NGC 2814 (II 868) and NGC 2820 (II 869) with 13.7 and 12.8 mag, respectively. The latter is extremely flat, owing the highest axis ratio of all Herschel galaxies (Table 2-55).

NGC	H	Sw	Date	V	Con	Size (')	R
2820	II 869	1004	3 Apr. 1791	12.8	UMa	4.1 × 0.4	10.3
5023	II 664	725	9 Apr. 1787	12.3	CVn	5.8 × 0.8	9.3
5981	-	843	25 May 1788	13.0	Dra	2.7 × 0.3	9.0
5907	II 759	842	5 May 1788	10.3	Dra	12.6 × 1.4	9.0
4244	V 41	714	17 Mar. 1787	10.4	CVn	16.6 × 1.9	8.7
5529	III 414	405	1 May 1785	11.9	Boo	6.0 × 0.7	8.6
5170	V 22	369	7 Feb. 1785	11.1	Vir	8.2 × 1.0	8.2
5714	III 675	734	12 Dec. 1787	13.4	Boo	3.2 × 0.4	8.0

Table 2-55: Extremely flat galaxies, discovered by Herschel; ‘R’ = axis ratio.

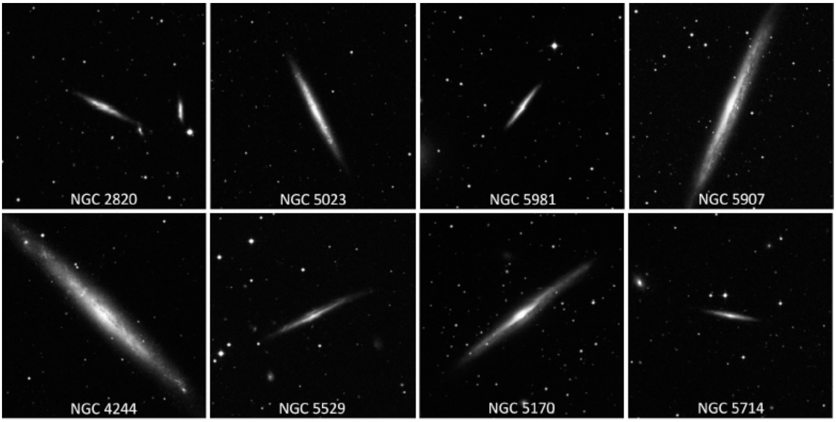


Figure 2-185: The extremely flat galaxies of Table 2-55. The companion of NGC 2820 is NGC 2814 (II 868); that of NGC 5714 is NGC 5717 (not seen). All images 10' × 10'.

In sweep 1006 (24 May), Herschel saw a star in Boötes, noting: "6 to 7m. Apparently enveloped in extensive milky nebulosity; but I am not sure whether there may not be a deception till I have another star about the same size." Because of its unknown nature, the object was catalogued as IV 71. However, there is no nebulosity. Nevertheless, the 6.0 mag star (HR 5633) was catalogued by Dreyer as NGC 5856. This is Herschel's second brightest supposedly 'nebulous' star after ε Orionis (NGC 1990).[771] A close double galaxy was found on the 26th in Boötes (sweep 1011), NGC 5851/52 (III 886/87). The companions of 14.1 and 13.6 mag are only 1' apart ("300 shewed them very plainly"); see Table 2-28.

Already on 23 May, Herschel had observed Venus with the 40-ft reflector – the ultimate challenge! He wrote:[772] "The light of Venus is so brilliant that it becomes very uneasy for the eye to bear it long." The 27th saw the third regular sweep ('3 sweep') with the large instrument; the former was more than a year ago. Only the globular cluster M 5 in Serpens was seen: "A beautiful cluster of stars, I counted about 200 of them, the middle of it is so compressed that it is impossible to distinguish the stars."

In September, three 40-ft sweeps were made near the ecliptic in Capricornus. Of course, Herschel's intention was the discovery of new planets. On the 25th we read about a 'Trial sweep for the

Ecliptic'. An eye-piece of 1.3 inches diameter with magnification 370 was used. Due to the focal length of 12 m, it was a 32 mm device. However, giving a field of 8.5', it was not a very promising tool for an ambitioning survey. Herschel first wanted to sweep with a breadth of 1° 1' but, due to the small field of view, he soon reduced it to 31', noting "the former [field] too broad for this power". Starting at 7:30 pm, he swept about half an hour from ρ Cap over 6° to 19 Cap. Nothing remarkable was seen. The "1st Sweep of the Ecliptic" was made on 28 September (breadth 31', power 370). The AR range was the same, now starting at υ Cap and again ending at 19 Cap; the strip was south of the former sweep. Except two double stars, nothing was seen. One was identified as IV 71. The other was thought as new until Caroline identified it in her compilation of all sweep stars as N10, found on 10 August 1784 in sweep 247.

Herschel had estimated that at a magnification of 1000, the 40-ft could not be effectively used for more than 100 hours per year in the English climate. Sweeping the entire sky, as done on the 20-ft, would thus take eight centuries! Therefore, he had to concentrate on selected areas. But another point was also critical. The large instrument took a lot more time to get ready for an observation than the 20-ft. The latter was ready for use in just 10 minutes and thus was very flexible when the sky suddenly became clear. In case of the 40-ft, much valuable time was lost in uncovering the mirror and preparing the bulky instrument for the nightly work. At least two assistants were needed to operate the motions and to take down the observations. Another problem was the stability of the mirror. Made as thin as possible, the enormous mass of 960 kg was subject to deformation, depending on tube elevation. This caused a focus shift and a distorted image. Moreover, the mirror must cool out a long time and was sensible to condensation of water vapor and, in the longer term, tarnishing. Herschel became increasingly frustrated. Dreyer later wrote:[773] "The 40 feet telescope should be used only for examining objects that other instruments will not reach. To look through one larger than required is loss of time, which in a fine night, an astronomer has not to spare." Later, even more time was wasted due to the many visitors, besieging the telescope, mostly with little interest in astronomy. With many of the nobles coming from Windsor Castle among them, poor Herschel

could not refuse their request.

On the 29th, a final sweep near the ecliptic was made, still farther south. Now a nebula was found, located 45' east of 19 Cap: “Suspected a very faint round nebula, gradually brighter middle, pretty large.” This is the 13.2 mag galaxy IC 1339 (Figure 2-174). However, the object (one of two discovered in Capricornus) remained uncatalogued.774 Hoping to find something more spectacular than faint nebulae, optimistic Caroline created a large folder, titled ‘Register of Sweeps in the Ecliptic with the 40 feet telescope’. It should show the sweep areas and – hopefully – new Solar System objects. That what’s the 40-ft was made for. Though 25 charts were prepared with a coordinate net and the line of the ecliptic, only two contain marked areas (Figure 2-186).775

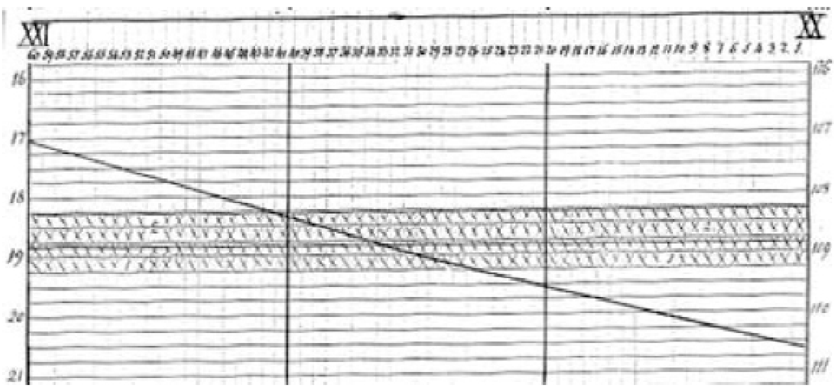


Figure 2-186: Chart of Caroline’s ‘Register of Sweeps in the Ecliptic with the 40 feet telescope’. The right axis is PD, the left declination (without sign). The line is the ecliptic. The swept areas are in Capricornus. It is one of two charts with entries, the other 23 are empty. This demonstrates the low effectiveness of the 40-ft.

Table 2-56 shows all 40-ft sweeps. Before starting a regular sweep, Herschel made tests in October/November 1788 with the usual breadth, lasting 20 minutes. In August/September 1789, three trial sweeps were made in Aquarius. The reason was simple, this was the terrain of Saturn at that time; the planet appeared on the sweep path (field of view 9.1'). Three non-stellar objects were seen, among them a new one: the galaxy NGC 7441. The first regular sweep, called ‘1 sweep’, was made in October (the galaxy NGC 779 was

seen). ‘2 sweep’ followed in December. After a break of 1½ years, Herschel performed ‘3 sweep’ on 27 May 1791 (the globular cluster M 5 was seen). In September, Herschel turned the 40-ft to the ecliptic in Capricornus. Three sweeps were made, yielding the galaxy IC 1339. The last sweep on 9 April 1793 (not named) brought the galaxy NGC 4831 in Hydra.

Date	Designation	Breadth	E (°)	Time (min)	Con	Power	FoV	Remarks / objects
28 Oct. 1788	test	2° 7'	38	15	Cet	280	9.1'	
23 Nov. 1788	test	2° 35'	87	20	Per	280	9.1'	north, above the pole
27 Aug. 1789	trial sweep	1° 0'	17	45	Aqr	280	9.1'	NGC 7392 (II 702)
28 Aug. 1789	trial sweep	1° 0'	31	45	Aqr	189	≈ 13'	**NGC 7441**
11 Sep. 1789	trial sweep	1° 0'	32	20	Aqr	280	9.1'	NGC 7585 (II 236)
20 Oct. 1789	1 sweep	1° 0'	31	25	Cet	280	9.1'	NGC 779 (I 101)
2 Dec. 1789	2 sweep	1° 30'	30	10	Cet	280	9.1'	
27 May 1791	3 sweep	1° 27'	41	10	Ser	280	9.1'	M 5
25 Sep. 1791	trial sweep of the Ecliptic	0° 15'	20	60	Cap	370	8.5'	
28 Sep. 1791	1st sweep of the Ecliptic	0° 31'	20	65	Cap	370	8.5'	double stars IV 71, N10
29 Sep. 1791	2nd sweep of the Ecliptic	0° 30'	20	65	Cap	370	8.5'	**IC 1339**
9 Apr. 1793		0° 32'	13	10	Hya	370	8.5'	**NGC 4831**

Table 2-56: 12 sweeps were made with the 40-ft reflector. The bold objects were new (see Table 2-47).

Back to the 20-ft sweeps of 1791. 30 May (sweep 1015) brought a remarkable nebula in Hercules: NGC 6166, catalogued as II 875. The 11.8 mag object is the dominant elliptical galaxy in the cluster Abell 2199 (Table 2-25). Herschel wrote: “Pretty bright, little extended, very gradually much brighter middle, small.” Another cluster member had already been found in sweep 715 on 17 March 1787. While sweeping with 300×, the 13.7 mag galaxy NGC 6158 (II 647) appeared in the small field of view. In sweep 1015, it was seen again, just before NGC 6166, lying 15' northeast, was found. Both galaxies are shown in Figure 2-187.

Figure 2-187: Galaxies of the dense cluster Abell 2199 in Hercules. Left: NGC 6166 (11.8 mag), the dominant member, has a multiple nucleus; Herschel found it on 30 May 1791. Right: NGC 6158 (13.7 mag), 15' northeast of the former, already seen on 17 March 1787 (both images 10' × 10').

A period without sweeps followed, lasting until 2 August. William was occupied with family affairs, so Caroline could observe with her sweepers. In a memorandum, dated 19 July 1791, she wrote:[776] "Since June the 9th 1790 I have kept no memorandum of my sweepings, tho' I believe I may say that I have neglected no opportunities whenever they offered; but, not meeting any comet, I looked upon keeping memorandums of disappointments as time thrown away. But as I intend to keep a regular Journal, when my new sweeper is finished, I will begin, by way of practice, to keep some sort of memorandum." The text is the first entry in Caroline's *Journal No. 4*. The document was written on 10 September 1828 and summarizes observations, made from 19 July 1791 to 22 January 1795. Most records are already contained in her second *Book of Observations* (*Journal No. 2*), covering the period from 7 July 1788 to 25 August 1797. However, two entries were not correctly copied: the dates 24 and 27 July 1790, must read 21 and 24. The opening text itself has some problems. Caroline's last observation, before the break of about one year, was made on 10 June 1790 (not on the 9th).

On 24 July, Caroline had her 'Messier marathon', observing seven M-objects in a single night: M 36, M 37, M 38, M 51, M 81, M 82

and M 94.[777] On 2 August, she swept “from the horizon thro’ the Pleiades, up as high as the head of Medusa. Left off with β Tauri.” Then the method was changed: “I continued with horizontal sweeps till the day light was too strong for seeing any longer. The horizontal sweeps were made from the club of Orion; to not far from the preceding feet of Ursa Majoris, and beginning from the horizon continued upwards from about 10 degrees.” Further observations were made on 4 September (“I swept this evening for to find the field of view again, where the [4th] comet was situated April 18th, 1790”) and 16 October, when M 13 and M 92 were viewed.

Meanwhile, on 25 August (sweep 1018), William discovered the planetary nebula NGC 6804 in Aquila, so it was not registered as such. Due to his impression (“easily resolvable, some of the stars visible”), the 12th mag object was catalogued as VI 38 (‘nebula or cluster of very close and faint stars’). The desciption is strange, because there is only a round nebula of 1' diameter. Perhaps he included the surrounding pattern of 13th mag stars (Figure 2-188).

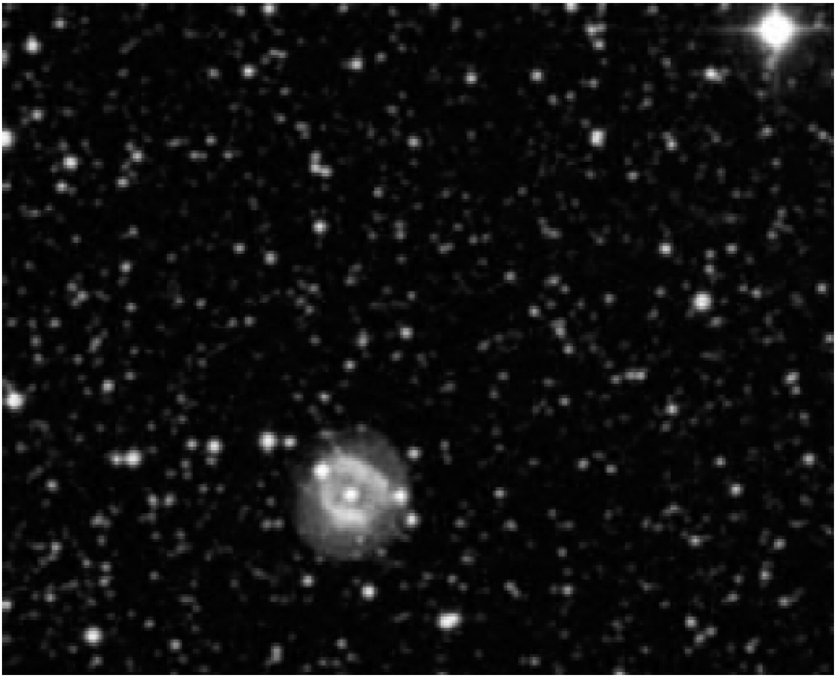


Figure 2-188: The small planetary nebula NGC 6804 in Aquila was found on 25 August 1791 and classified as a 'star cluster'. The star 5' northwest has 9.3 mag.

Sweep 1019 on 27 August was the last made in 1791. Thereafter, Herschel mainly observed Saturn with the 20-ft in 41 nights. On 25 September, while observing the ringed planet, he saw "a nebula, certainly bright, round, a nucleus in the middle, about 2' diameter […] It is most probably the 252nd III class. It is about 5 [times] of my fields of view following Saturn."[778] Indeed, this was the 10.4 mag galaxy NGC 488 (III 252). In that night, the planet was 1.5° west. On the 26th, he wrote: "The nebula of last night, is in the same place where I saw it."

Caroline, having time for observing with the large sweeper, was once again rewarded on 15 December – with her 5th comet! She wrote:[779] "Since Oct. 16 I have swept at different times whenever the weather or time would permit, but not finding anything new I kept no account of the places I swept." However, at 8:15 pm we read: "I perceived a Comet in the breast of Lacerta, and by way of securing my Brother's observations upon it, I will transcribe them from the loose papers upon which they were noted down."[780] The 7.1 mag comet was in Lacerta ($\delta = 43°$), 54° above the western horizon. At 9:10 pm the position was noted: "By the finder it is about ¾° south of 2 Lacerta in a line parallel to δ Cephei and the 9th Lacerta."

About 30 minutes later, William joined Caroline. She wrote:[781] "My Brother settled the comets place and its rate of moving, with the seven feet reflector. At 9^h 42' 4.8" true mean time, it preceded a small telescopic star 11.9" in time and 2' 41" south of the same. The place of this star was determined the 16th of Dec." The time was taken with the (sidereal) '20-ft clock'. Late after midnight (now the 16th), at 5:48 am, "the Comets place was determined by my 5 feet Newtonian Sweeper, carrying an equilateral triangle in the focus of the eye-glass."[782] (Figure 2-189). Now 'Alexanders clock' was used, showing the mean time. The observations ended at about 7:50 am and the siblings urgently needed sleep.

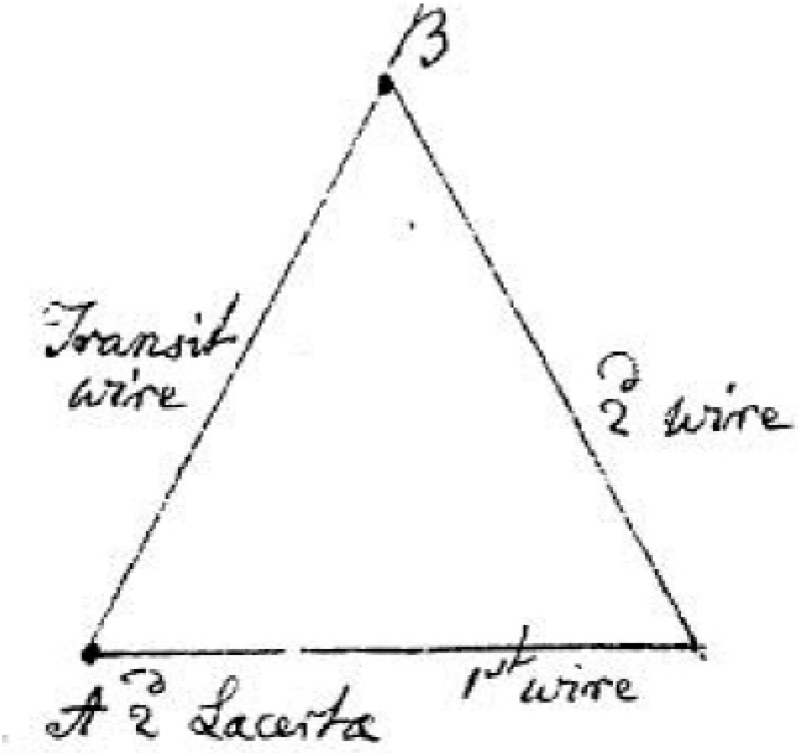


Figure 2-189: The two-lens ('double') eye-piece of the large sweeper was equipped with a triangular wire.

The next evening, at 8:25 pm, William wrote:783

I examined the comet my sister discovered last night. The twenty feet reflector shewed a great light pretty regularly scattered about a condensed part of 5 or 6 [arc]seconds in diameter; which resembled a kind of Nucleus but had not the least appearance of a solid body. Beside the scattered, and gradually diminished light, which reached nearly to a distance of 3 [arc] minutes very way beyond the brighter center, there was also a faintly extended, ill defined, pretty broad ray, of about 15 [arc] minutes in length, directed towards the north following part of the heaven, which might be called the tail of the Comet.

For this observation, the telescope was rotated to the west by the 'round motion'. William never saw the comet again and devoted

himself to Uranus. Caroline stayed with her comet, following it until 25 January 1792, then standing low at the horizon in Pisces.

There were several guests at Slough in the last three months of 1791. Caroline noted in her table of visitors: "Mr. Brinckley saw some objects October 18, 1791. Mr. Greatheed and his brother saw the sixth satellite of Saturn etc., Oct. 23, 91 in the 40ft Telescope. Repeated their observations on Nov. 4, 1791. Professor Blumenbach from Göttingen saw some objects Dec. 1791."[784] The latter came again to Slough on 26 December.

2.8.4. Summary of 1790–91

Table 2-57 gives the statistical data of the sweeps made in 1790 and 1791. The year 1790 started with no. 933 on 17 February and ended with no. 991 on 29 December. 1791 started with no. 992 on 3 January and ended with no. 1019 on 27 August. In 1790, the lowest elevation was reached and William saw his most southern non-stellar object, 6° above the horizon. In 1790, Caroline discovered her 3rd and 4th comet. The large sweeper, built by William, was ready to use. A new eye-piece with 360× was used at the 20-ft. William watched a total lunar eclipse. His main discovery was the 'star with an atmosphere', NGC 1514 in Taurus. In 1791, the important paper on 'nebulous stars' was published, claiming the existence of nebulous matter. William made his 1000th sweep and watched his first solar eclipse. A third regular sweep was made with the 40-ft, followed by sweeps near the ecliptic. Caroline discovered her 5th comet.

Category	1790	Remarks	1791	Remarks
number of nights	33		19	
longest continuous period (days)	5	3 – 7 Sep.	8	23 – 30 Sep.
longest break (days)	214	18 Jul. 1789 – 17 Feb. 1790	64	30 May 1791 – 2 Aug. 1782
number of sweeps	59		28	
sweeps per night (maximum)	7	9 Oct.	4	2 Apr.
mean night (hours)	2.7		2.1	
longest night (hours)	8.2	9 Oct. (observing 4.2 hours)	5.6	2 Apr. (observing 2.8 hours)
lowest elevation (°)	6	9 Oct., *record*	11	7 Mar.
highest elevation (°)	90	PD 39°	87	PD 42°
lowest PD (°)	23		17	
observed objects	184		71	
objects per night (mean)	5.6		3.7	
sweeps without objects	17		13	
new objects (all)	130		38	
uncatalogued objects	-		3	Table 5-5
re-observed objects	54		33	
most productive night	18 Mar.	29 objects	2 Apr.	22 objects
first object		NGC 3621 (Gx Hya); Figure 2-181		NGC 2506 (O, Mon)
last object		NGC 257 (Gx, Psc)		NGC 1339 (Gx For); Figure 2-174
brightest object (mag)	6.2	NGC 1545 (OC Per)	6.0	NGC 5856 (star Boo)
faintest object (mag)	14.1	NGC 4511 (Gx UMa)	14.1	NGC 5851 (Gx Boo)
smallest object (")	41	NGC 1985 (RN Aur)	42	NGC 6103 (Gx CrB)
discovered multiple systems	1	1 pair	3	3 pairs
observed Messier objects	3		3	
new double stars	9		4	
new garnet stars	2		-	
star gages	15		1	
vacant places	1		-	

Table 2-57: Sweep statistics for 1790 and 1791.

2.9. Observations in 1792–94, before sweeping was halted for three years

2.9.1. More sweeps, a 40-ft discovery and Caroline's 6th comet

Already on 12 January, the Herschels received a guest from Göttingen Observatory, showing him Saturn and its satellites: "Professor Seyffer saw them likewise, and he also saw the shadow of the ring upon Saturn."[785]

There was no sweep in the first quarter of 1792. William observed Saturn and Uranus with the 20-ft and checked double stars with the 7-ft. In continuation of the *Fixt Stars* series, which was closed 12 July 1784 with No. 7, Caroline opened a book called *Review No. 5*, containing observation of objects beyond the planets, made with different telescopes. The volume started on 14 February 1792 and ended on 31 January 1800. Already the second entry (17 February) describes the discovery of a 'deep garnet' star with the 7-ft, later

identified as 6 Gem (6.3 mag); see Table 2-11. M 35 was also viewed. On 5 March, William interrupted his observations for two weeks. The reason was as simple as it was enjoyable: John's birth on the 7th (Figure 2-190).[786]

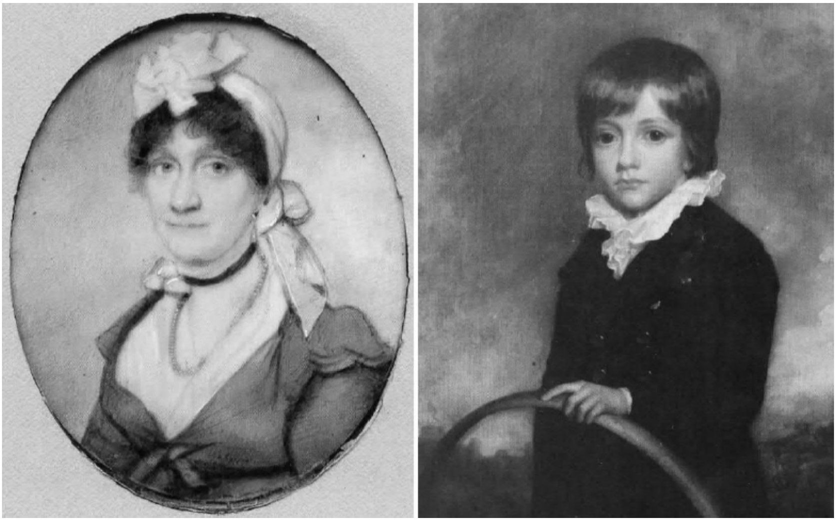


Figure 2-190: William's wife Mary (Lady Herschel) and their son John, drawn at the age of seven.

On 29 May, William and his Polish friend Jean-Baptiste Komarzewski started a leisure tour to northern England and Scotland, lasting 28 days.[787] On 2 June, James Watt was visited at his factory near Birmingham.[788] On 3 July, William received the LL.D. (honorary doctor of laws) from Glasgow University.[789] On the 13th, John Mitchell was visited at his home in Thornhill. The impressive 29.5-inch reflector was examined: "We saw Mr Mitchell's telescope; it is on an equatorial stand; being without cover behind. I put my hand into the opening and felt the face of the object speculum so wet as to moisten my fingers. Mr Mitchell was very indifferent in health."[790]

In the first quarter, Caroline used the large sweeper to look for comets or other interesting objects – with zero result. The first sweep (1020) of the year was made on 11 April; as usual, her assistance was needed. In strong moonlight, nothing was found. In sweep 1021 on 20 April, Arcturus, the second brightest northern

star, crossed the field of the 20-ft: “The star was so bright that I could not hardly look at it.” Although every Flamsteed star in the area was noted on Caroline’s sweep plan, an observation was not always certain. It depends on the time needed to describe new objects. Any stop altered the sweep path. Arcturus was the brightest star ever seen in the 20-ft reflector.791 Herschel needed a few minutes to get ready for the next view. He discovered a nebula, located only 1.3° southeast of Arcturus: the 12.8 mag galaxy NGC 5492 (II 876). This is one of five cases, in which a non-stellar object was observed within 2° of a very bright star (Table 2-58).

Star	V	NGC	H	Sw	Date	V	Con	Type	Dist	Remarks
Arcturus	-0.05	5492	II 876	1021	20 Apr. 1792	12.8	Boo	Gx	1.3' NW	
Capella	0.08	1883	VII 34	645	11 Dec. 1786	12.0	Aur	OC	1.6' NE	
Antares	0.96	6144	VI 10	223	22 May 1784	9.0	Sco	GC	0.6' NW	near M 4
Spica	0.97	5146	III 115	210	9 May 1784	12.6	Vir	Gx	1.2' SE	11 Mar. 1788 (sw 819)
Regulus	1.39	3153	III 53	177	19 Mar. 1784	12.7	Leo	Gx	1.3' SE	12 Apr. 1784 (sw 188)

Table 2-58: Non-stellar objects, found within 2° of a very bright star (both were seen in the mentioned sweep).

When William was on his tour, Caroline certainly wanted to take the opportunity to observe with the large sweeper, but there were some other tasks: “My brother having desired me by way of practice to settle the stars α Virginis, α Persei and Castor, by some neighbouring stars in Wollaston’s Catalogue; I made last night [2 May] an attempt of taking their places, therefore no sweeping could be done.” She used the “5 feet Newtonian Sweeper & equilateral triangle”, i.e. the 2-lens (‘double’) eye-piece with triangular wires (see Figure 2-189). Nevertheless, Caroline found time for sweeping, performed both vertically and horizontally. On 11 and 15 June she observed the galaxy pair M 81/82 in Ursa Major.

The latter date (15 June 1792) was remarkable: the great composer Joseph Haydn visited Slough, snatching a day from his London engagement.792 However, he must have been disappointed not to meet his fellow musician William Herschel, who was in Scotland at that time. However, Caroline came over from her cottage and entertained the prominent guest. He marvelled at the 20- and 40-ft telescopes. After Haydn left, Caroline used the short, very clear night for sweeping from the roof ‘observatory’.

On 14 August, sweep 1022 was made without any problems. This

would change dramatically on the 19^{th}, when sweep 1023 ended abruptly because “The Gallery broke down.” Fortunately, nobody was not hurt. Only three days later, the construction was operational again (sweep 1024 was used for ‘gaging’). On 8 September, Herschel observed with the 40-ft.[793] At 9:00 pm, α Cap was seen. 45 minutes later and 1° more north, the planetary nebula NGC 7009 entered the small field of view: “Saw the nebula near ν Aquarii; its light appeared of a greenish cast, but having been much exposed to the light of candles my eyes were not in a proper condition to judge in partially of colours.”

On 13 September, “Mr. Bates observed the 6^{th} satellite of Saturn etc.”, probably with the 20-ft.[794]

On the 15^{th} (sweep 1027), Herschel noted: “8 m. Double. A faint milky ray south preceding joins to the double star; it is about 8' long, and 1½' broad.” The star has 7.2 mag; the ‘milky ray’ is the brightest, arched part of the emission nebula NGC 6888 (IV 42) in Cygnus, known as Crescent Nebula (Figure 2-191).[795] About 10 minutes later, M 29 was seen for the first time in the 20-ft: “A cluster of very coarsely scattered, very large stars; not rich.” The next sweep (1028), made on the 16^{th} in the north (Cepheus), was the last of 1792. Nothing was found.

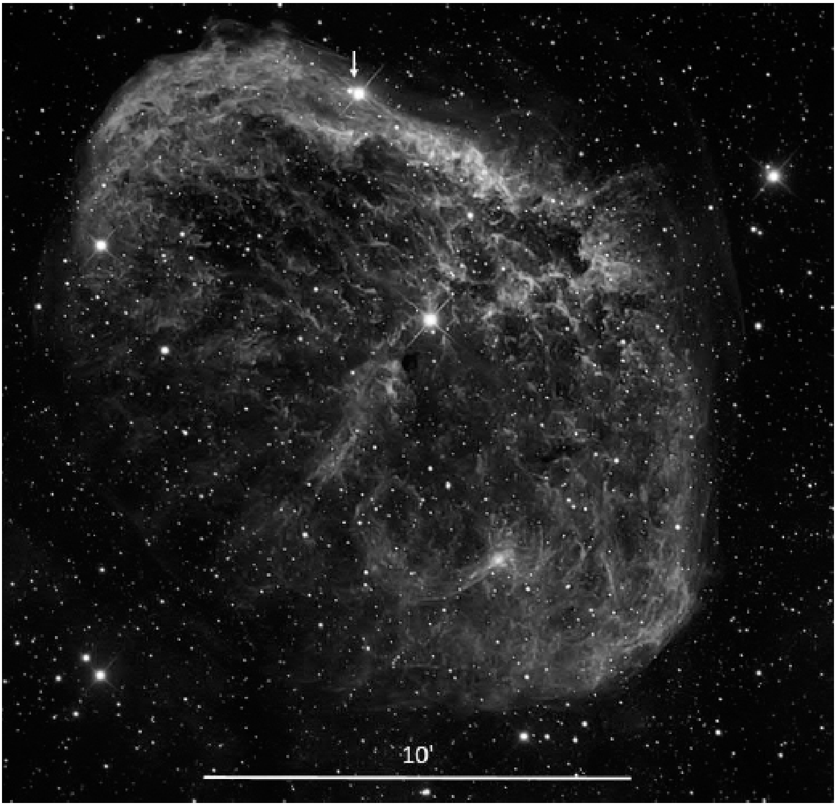


Figure 2-191: The Crescent Nebula NGC 6888 in Cygnus, found on 15 September 1792. The mentioned double star (7.2 mag) is marked by an arrow; Herschel saw the part immediately southwest.

What happened in the rest of the year? William observed the Sun, Saturn and double stars, mainly with the 7-ft. Meanwhile, Caroline inspected several Messier objects: M 11, M 13 and M 92, using both the large and small sweeper. The compressed open cluster M 11 in Scutum was first mistaken as a comet (7 November).

Caroline's celestial tour was continued in January 1793, viewing M 15, M 30 and M 33. On the 13th, William joined her: "My Brother having received an account of a Comet, discovered by Mr. Gregory in Nottinghamshire on Jan. the 8th. I directed my sweeper to the place where expected to have moved to since the 8th but as it happened to be overcast by clouds in that neighbourhood, I looked about with the naked eye and soon saw a pretty large comet near

Cassiopeia [on the 13^{th} with 1.9 mag]. My brother viewed it with the 7ft."[796] 'Comet Gregory' was observed until 18 January. A last trial on 5 February was in vain: "Being informed by Dr. Lind that the comet was still visible in Aries, I swept for it the whole sign about 20° below & above the Ecliptic; but could not find it, my assistance being wanted at the 20 feet telescope. Left off looking for it."[797] Concerning the mentioned "assistance": no sweep was made that night. Obviously, Caroline was in place, when William viewed Uranus with the 20-ft, meanwhile located 5° northwest of Regulus. The observation started at about 9:30 pm.

The first sweep of 1793 (1029) was made on 3 February. The open cluster M 36 in Auriga was observed for the first time with the 20-ft. In the next night (sweep 1030), M 38 and M 36 were seen; the 'reference star' for M 36 was M 38. A new object was found between them: NGC 1931 (I 261), also referenced by M 38. Herschel noted: "Very bright, irregularly round, about 4 or 5' diameter, seems to have one or two stars in the middle or an irregular nucleus, the chevelure diminishes very gradually." The emission nebula is located 1° west of M 36. It includes four 11–12 mag stars. In the following sweep (1031, same night), made in Gemini, a double and a triple nebula were found. Herschel first saw a pair of 13^{th} mag galaxies, NGC 2289/90 (III 897/98), distance 2.5'.[798] The following trio is within 7' and consists of NGC 2385 (III 900), NGC 2388 (III 901) and NGC 2389 (III 703). The latter galaxy, was already discovered in sweep 807 (5 February 1788). In that night, the two other galaxies (about 1 mag fainter) were probably missed due to haziness; for NGC 2389 it is noted "may be a patch".

On 4 March (sweep 1033), Herschel revisited Antlia, now making his only discovery in the southern constellation. However, it was remarkable find, only 8° above the horizon: the 9.5 mag face-on galaxy NGC 2997, catalogued as 'large nebula' V 50 (Figure 2-192). He wrote: "Very faint, very large, large brighter middle, little extended, about 8' long and 5 or 6' broad, a little from sp to nf, about 10 or 15°." As reference star "55 (ε) Pixidis naut. of Bode's Cat." was used.

Sweeps 1036–39 (6 to 9 April) were made in the north, above the

pole. In the first, the ‘large nebula’ V 51 was found in Draco: “Very faint, large brighter middle, much extended, about 25' long, and losing itself imperceptibly, about 6 or 7' broad, from 70° np to sf.” This is the 9.6 edge-on mag galaxy NGC 4236 (Figure 2-192). It is smaller than described. In the same night (sweep 1037), two more edge-on galaxies were discovered in Draco, though smaller and fainter. The first NGC 3879 (II 881); the 13.0 mag galaxy has an axis ratio of 5 (it was not found in sweep 1105 on 7 December 1801). The second is NGC 4749 (III 907) with 13.5 mag and ratio 6.

Figure 2-192: The large face-on galaxy NGC 2997 in Antila (left) was found on 4 March 1791. The ‘magellanic’ galaxy NGC 4236 in Draco (right) was found on 6 April 1793. Herschel overestimated the extension.

In sweep 1038 (8 April), three ‘very bright nebulae’ in Ursa Major were observed and sketched: NGC 3206 (I 266), NGC 3458 (I 268) and NGC 3488 (I 269); see Figure 2-193. These are galaxies of 11.9, 12.3 and 12.9 mag, respectively. The sweep also brought an uncatalogued nebula in Ursa Major: “Suspected, very faint, very small. As I could not follow, I could not verify it.” The object was perceived at the western side of the field, just moving out. When observing in the north, the ‘side motion’ was blocked towards the west, so Herschel could not follow. Actually, he has found MCG 10-16-61, a 14.2 mag galaxy – an incredible observation (Figure 2-194).

In the following night (sweep 1039), another uncatalogued object was seen in Ursa Major: “2 very faint stars [U1018, U1019] pretty close together. I suspected them to contain very faint nebulosity, but 240 shewed them clear of it.” Actually, there is a 15th mag star and a small, faint nebula (distance 22") at the place. The latter is UGC 5722, a 14.6 mag galaxy – incredible again (Figure 2-194). The sweep ended at about 10:10 pm. At 10:30 pm, Herschel was already standing on the gallery of the 40-ft. The south oriented tube pointed to Hydra. It is unknown, why this constellation was chosen. Seven minutes later and only 12° above the horizon, a faint, round nebula crossed the field of view: the 12.5 mag galaxy NGC 4831. The ‘sweep’ ended a minute later. This non-stellar object was the third and last, discovered with the 40-ft (Figure 2-174, Table 2-56) – what a poor yield! The main problem when using the large reflector for sweeping was the small field of view; even for the lowest magnification it was no more than 9'. This caused a narrow sweep path. To reduce the inevitable gaps, the breadth must be small (about 30') and the sweep speed high – relaxed working looks different.

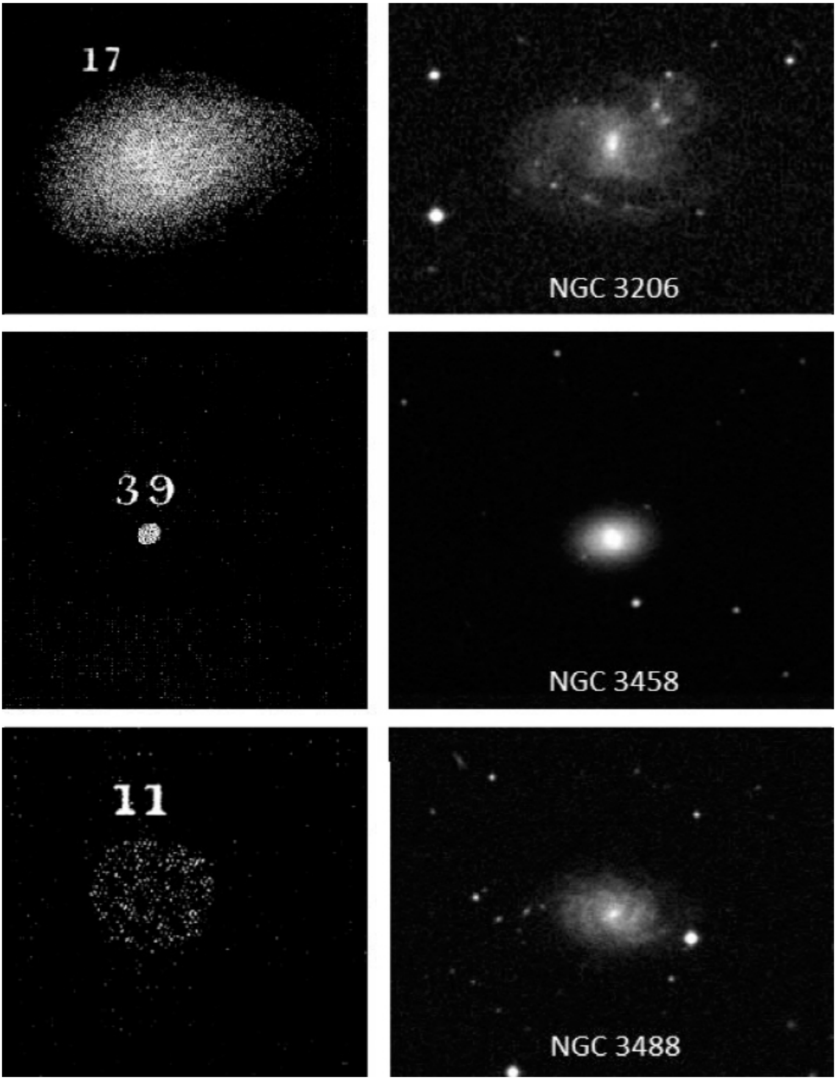


Figure 2-193: Three galaxies in Ursa Major, found and sketched on 8 April 1793: NGC 3206, NGC 3458 and NGC 3488.

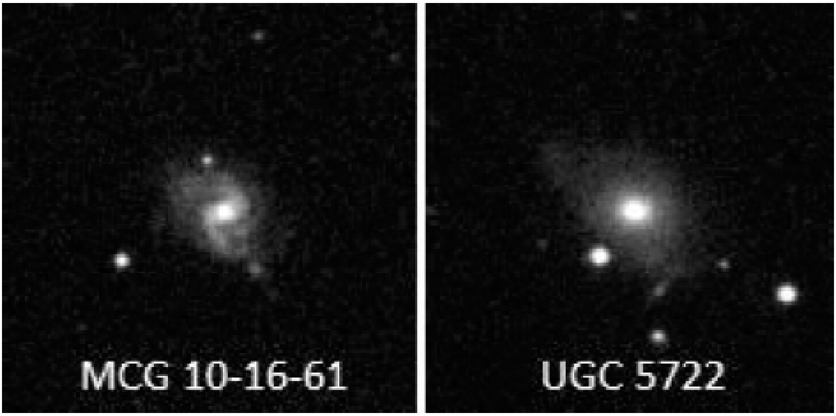


Figure 2-194: Two astonishing observations in Ursa Major: the galaxies MCG 10-16-61 (14.2 mag) and UGC 5722 (14.6 mag), discovered on 8 and 9 April 1793.

On 12 May (sweep 1042), another uncatalogued object was found: “2 very faint stars with nebulosity suspected between them.” The 11th mag stars in Boötes were catalogued as U^{1022} and U^{1023}. The position fits to the 13.4 mag galaxy NGC 5519. Curiously, a duplicate case happened only six minutes later: “2 very faint stars [U^{1024}, U^{1025}] with suspected nebulosity, but 300 shewed them free of it.” The nebulosity exists, it belongs to the 13.1 mag galaxy NGC 5575. In the same night (sweep 1043), Herschel discovered the globular cluster M 107 (NGC 6171) in Ophiuchus, one of the seven added Messier objects. He catalogued the 7.8 mag object as VI 40; it is pretty loose (concentration class X). We read: “Resolved, about 5 or 6' diameter, gradually more compressed towards the center.” A very close pair was found in sweep 1044 (same night); they must have been seen in a single field, though it is not noted as such. These are the 12.3 mag galaxies NGC 5257/58 (II 895/96) in Virgo, only 1.3' apart.

There was no sweep from 7 June to 25 August. As usual, Caroline used the break for observations with the large sweeper. Again, her targets were Messier objects: M 1, M 31, M 81, M 82 and M 94. During her sweeps, she rediscovered two of William’s nebulae: the 9.6 mag galaxy NGC 4449 (I 213) in Canes Venatici (see section 1.9) on 8 July and the 8.5 mag galaxy NGC 2403 (V 44) in Camelopardalis on 31 July. In October 1793, the Astronomer Royal,

Nevil Maskelyne, wrote about Caroline:[799] "She will thus sweep a quarter of the heavens in one night. The Dr [Herschel] has given her written instructions how to proceed, and she knows all the nebulae [listed by Messier] at sight, which he esteems necessary to distinguish new Comets that may appear from them. Thus, you see, wherever she sweeps in fine weather nothing can escape her."

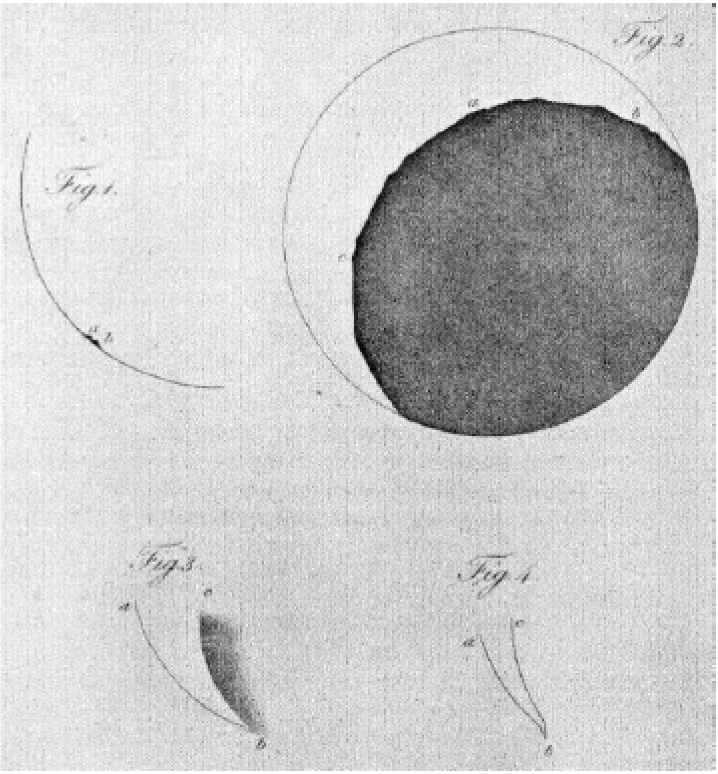


Figure 2-195: Sketches of Herschel's second partial solar eclipse, observed at Slough on 5 September1793 with the 7-ft. They were published in 1794. The lunar edge shows some structure.

On 5 September, Herschel watched his second solar eclipse; it was again partial (see Table 2-54). Using the 7-feet reflector, he wrote: "I saw two mountains of the Moon enter the disk of the Sun." He made some sketches, published in 1794 (Figure 2-195).[800]

In sweep 1049 on the 6th, Herschel (once again) encountered a 'beautiful phenomenon': "A bright point, little extended, like two

points close to one another; as bright as a star of the 8 to 9 magnitude surrounded by a very bright milky nebulosity suddenly terminated, having the appearance of a planetary nebula with lucid center. The border however is not very well defined. It is perfectly round and I suppose about ½' in diameter. It is of a middle species between the planetary nebulae and nebulous stars." He had discovered NGC 6826 (IV 73) in Cygnus, now known as the Blinking Planetary; the 8.8 mag object hosts a 10.6 mag central star (Figure 2-196). The curious name is due to a visual effect, when viewing the planetary nebula with a small telescope. With direct vision the central star dominates and the surrounding nebula disappears. With indirect (averted) vision, things are reversed: the nebula appears, the star steps back. Thus, the celestial duo 'blinks' as the observer's view changes.

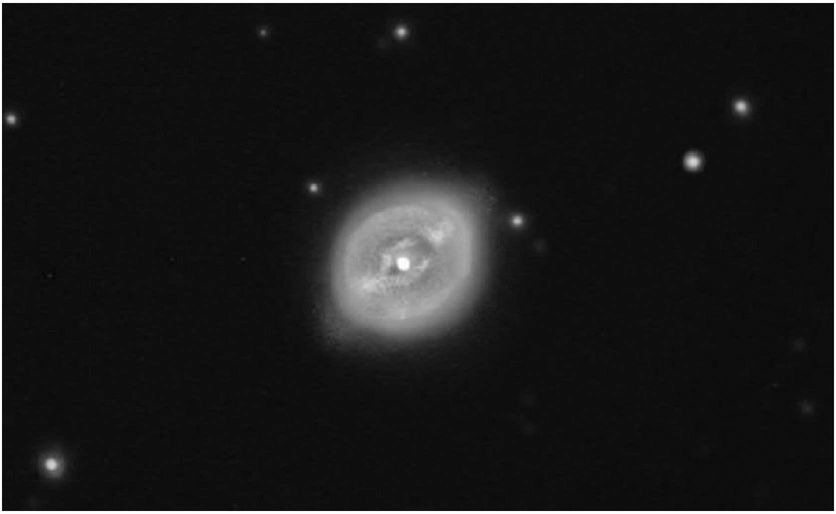


Figure 2-196: The Blinking Planetary

NGC 6826 in Cygnus and its central star, found on 6 September 1793 – another 'beautiful phenomenon'.

In the same night (sweep 1050) "a telescopic meteor passed through the field of view, of the size of a star of the 9th or 10th magnitude, from north-following to south-preceding." Only 14 minutes later another one crossed the field. Due to the date (early September), both could be stragglers of the Perseids.

On 10 and 11 September, Herschel hosted Patrick Wilson a second time (after 27 September 1783):

[10th] Professor Wilson of Glasgow [Observatory] saw, with my 20 feet Reflector, the 15th Nebula of the Connaiss. des temps resolved into stars. He saw my planetary nebula No. 18 of the 4th class [NGC 7662 in Andromeda], and found it as I have described it. He also saw No. 1 in the 4th class [NGC 7009 in Aquarius] as described in my catalogue. He saw the 1st, 2nd, 3rd, 4th & 5th Satellites of Saturn. I also saw the 6th & they answered to their calculated places. With the 7 feet Reflector I shewed Mr. Wilson δ Serpentis, ζ Aquarii, ν Andromeda, Cor Caroli, p Serpentarii [70 Oph]. In order to shew the spurious diameter of the fixed stars I reduced the aperture of the 7ft reflector to 3 inches and used a power of 460; then directing it to Aquila this diameter became very visible.

[11th] I viewed the 51st neb. of the 4th class [NGC 6818 in Sagittarius]. It has a small star np. and another nf. but the preceding one is the nearest.

The last sweep (1056) of the year, made on 5 October, brought nothing new. That is not true for the remaining, non-sweeping period. As usual, the highlight was again set by Caroline. On 7 October, she discovered her 6th comet (using the large sweeper):[801]

About 8 o' clock I perceived an object which looks like a Comet, within 2 degrees from the 1st (δ) Ophiuchi. Clouds coming on immediately it was impossible to be certain about the star. Nor could I for want of another look say how the object was situated with this neighbouring star (The 1st (δ) Ophiuchi). When I had the first glimpse of the object it appeared pretty bright, and there was no very considerable star in the field with, and only accompanied by a glimmering of some small stars.

The 5.6 mag comet was 7° above the western horizon, 3° northwest of δ Oph (2.7 mag). On 8 October, Caroline noted: "The object of last night is a Comet." William confirmed it:[802] "In the finder of my 7 feet telescope I took the passage over the wire." She added: "It is fully as bright as the 5th of the conoiss. des temps [M 5 in Serpens], and I think it is a little larger." Alas, the weather was totally cloudy until the 14th. Though, trying to find the object until the 27th,

Caroline always looked in vain – the comet was never seen again. It later turned out that Messier had discovered the object already on 27 September in Hercules.

During the rest of the observing year, which ended for the siblings on 29 December, Saturn was viewed with the 20-, 10- and 7-ft. In the garden at Slough, the two smaller telescopes were near the 20-ft, allowing an easy change. Meanwhile, the 40-ft stood unused aside for the most of the time. On 28 October, Caroline wrote:

This evening, at the intervals my brother was not observing with the 20 feet [for sweeping], I practised to find known objects readily in my telescope; but I met with my impediments. The telescope is raised too high and some steps are wanted, and a finder perhaps may be better than the director. My brother directed the sweeper very readily to several of the nebula of the Connoiss. des temps; and in looking for the 97th [M 97 in Ursa Major] found that it not exist, or at least is not visible with this instrument.

On 1 January 1794, William observed Saturn and Caroline "looked at several nebulous patches which had a cometic appearance to the naked eye". In the first sweep of the new year (1057), while observing in Perseus and Auriga, William suspected a "faint nebulosity over the whole breadth of the sweep". We read: "When I left off, I found the sky covered with a faint haziness; so that the apparent nebulosity may be owing to that cause; though the stars I saw were not affected with halos as they generally are when surrounded by haziness."

In February and March, Herschel observed Saturn and Uranus. The night of 22 March was special. While viewing the latter with the 20-ft and a new eye-piece, giving 320×, he noted: "¾° following and ½° north of the planet is a pretty large red star, with a faint nebula about 3' north of it." He had discovered the 13.4 mag galaxy NGC 3107 in Leo. It was catalogued as II 898, which is unusual for objects, not found in a sweep. The red star has 7.8 mag; Uranus was 1° southwest. The ensemble was seen at altitude 51° / azimuth 159° (thus still away from the main house; Figure 2-141). However, only 20' west of Uranus was another galaxy NGC 3080 (13.6 mag), which was not seen. This would be different on 1 April, when Herschel found "a very faint nebula. It precedes the Georgian planet

16" [seconds] in time, and is about 2' more north". Both objects were in a single field. The AR difference was correct, but the galaxy 4' west. It was catalogued as III 934. The nebulae II 898 (NGC 3107) and III 934 (NGC 3080) were entered in the third catalogue, Uranus was mentioned as 'reference star' (Figure 2-197; Table 2-27).

On 19 April (sweep 1058) the 13.9 mag galaxy NGC 3734 (III 935) in Crater was found. A break of 163 days followed until the next sweep (1059) on 29 September. In the first 69 days, William was absent. Then, in July, he observed Jupiter with the 10-ft. Meanwhile, Caroline used her sweepers for M 3, M 12, M 13, M 81, M 82 and M 92. Sweeps 1059 (29 September) to 1063 (18 October) were made above the pole.[803] On 14 October (sweep 1060), Herschel discovered the red star V419 Cep (see Table 2-11): "8m, of a very deep garnet colour, U1040." On the 15th (sweep 1062), the last (true) planetary nebula was discovered: NGC 7076 (III 936) in Cepheus. The 13.5 mag object was described as "very faint, easily resolvable". However, there is no optical reason for the term 'easily resolvable'.

Figure 2-197: While observing Uranus on 22 March (a) and 1 April 1794 (b) in Leo with the 20-ft, Herschel found NGC 3107 (13.4 mag) and NGC 3080 (13.8 mag). The arrow shows the mentioned red star. The field is 1.2° × 0.7°.

Figure 2-198: On 18 October 1794, Herschel discovered the bright emission nebula NGC 7023 in Cepheus with its 7.2 mag central star. The night was the last before sweeping was halted for three years.

On 18 October the last sweep (1063) of 1794 was made. It brought NGC 7023 (IV 74) in Cepheus, Herschel's emission nebula with the highest declination (67°): "7m. A star very much affected with nebulosity that more than filles the fild [sic], it seemed to extend to at least a degree all around; smaller stars such as 9 or 10m of which there is a great number, are perfectly free from this appearance; but every thing about the telescope being very damp, I have some suspicion of a deception." The central star of the conspicuous nebula is the variable V380 Cep (Figure 2-198). About 40 minutes later, a similar object was found, though much smaller: NGC 7129 (IV 75), Herschel's last emission nebula, described as "3 stars about 9m involved in nebulosity, the whole takes up a space of about 1½' in diameter; 2 other stars of the same size and very near, are not inclosed in the nebulosity." Two minutes later and 25' southeast, the open cluster NGC 7142 (VII 66) was discovered.

Then Herschel stopped sweeping. What was the reason? Did he think the sky was sufficiently covered and there was nothing left? Certainly not. There were still larger areas near the pole, and, even more important, the next magical number of 1000 new objects had not yet been reached – the current number was 424. We will see that his interests changed to other subjects – though still

astronomical.

During the rest of the year, William observed Saturn with the 20-ft. The 7-ft was used for Venus and Messier objects; M 1, M 2, M 15, M 27, M 29, M 30, M 33–38, M 71 and M 74 were viewed. Caroline, using the large sweeper on the flat roof of her cottage, saw M 14, M 51 and M 56. On 24 October, the globular cluster M 14 in Ophiuchus was first taken for a comet. The last observation of 1794 was made by William, observing the Sun with the 7-ft.

2.9.2. Summary of 1792–94

Table 2-59 summarize the sweeps made in 1792–94. The year 1792 starts with sweep 1020 on 11 April and ends with sweep 1028 on 16 September. 1793 starts with sweep 1029 on 3 February and ends with sweep 1056 on 5 October. 1794 starts with sweep 1057 on 2 January and ends with sweep 1063 on 18 October. No new record was set. In 1792, John was born. The gallery of the 20-ft crashed. Arcturus was the brightest star, ever seen in the 20-ft. The *Review* series was continued with No. 5. During a tour to northern England and Scotland, William got the honorary doctorate (LL.D.) from Glasgow University. In 1793, he watched his second solar eclipse and Caroline discovered her 6th comet. 1794 brought two galaxies, found near Uranus. Then sweeping was terminated for about three years.

Category	1792	Remarks	1793	Remarks	1794	Remarks
number of nights	9		23		6	
longest continuous period (days)	2	12 – 14 February	6	3 – 9 April	3	17 – 20 August
longest break (days)	228	27 Aug. 1791 – 11 Apr.	120	16 Sep. 1792 – 3 Feb.	163	19 Apr. – 29 Sep.
number of sweeps	9		28		9	
mean night (hours)	0.9		1.5		0.9	
longest night (hours)	1.4	11 Apr.	4.5	12 May (obs. 1.6 h)	1.8	18 Oct.
lowest elevation (°)	57	11 Apr.	9	4 Mar.	26	19 Apr.
highest elevation (°)	86	PD 38°	89	PD 35°	79	PD 45°
lowest PD (°)	51	11 Apr.	9	4 Mar. / 19 Apr.	22	18 Oct.
observed objects	12		105		12	
objects per night (mean)	1.3		4.6		2.0	
sweeps without objects	4		12		3	
new objects (all)	8		81		7	
uncatalogued objects	-		6	Table 5-5	-	
re-observed objects	4		24		5	
most productive night	20 Apr.	5 objects	8 Apr.	23 objects	19 Apr.	4 objects
first object		NGC 5174/75 (Gx Vir)		NGC 1931 (EN+OC Aur)		NGC 1579 (RN Per)
last object		NGC 6824 (Gx Cyg)		NGC 7251 (Gx Aqr)		M 33 (Gx Tri)
brightest object (mag)	12.2	NGC 6824 (Gx Cyg)	7.0	NGC 2571 (OC Pup)	9.1	NGC 2392 (PN Gem)
faintest object (mag)	13.5	NGC 5737 (Gx Boo)	14.8	NGC 3671 (Gx UMa)	13.9	NGC 3734 (Gx Cra)
smallest object (")	66	NGC 5702 (Gx Boo)	30	NGC 3671 (Gx UMa)	42	NGC 3107 (Gx Leo)
discovered multiple systems	-		4	4 pairs	-	
observed Messier objects	1		14		-	
first observation	-		1		-	
new double stars	7		7		1	
new garnet stars	1		-		1	
star gages	8		3		-	
vacant places	-		-		-	

Table 2-59: Sweep statistics for the years 1792 to 1794.

292 Caroline helped her brother in making mirrors. In the summer 1784 she wrote: “In my leisure hours I ground seven-foot and plain mirrors from rough to finishing down, and was indulged with polishing and the last finishing of a very beautiful mirror for Sir William Watson.” Herschel Mrs. J. (1876: 56).

293 The story about Herschel’s search for nebulae was also told, though in less detail, by Hoskin (1979, 2011c).

294 Bennett (1976a, b).

295 The term ‘quadrant’ has two meanings: the angle Q and a device (measuring Q), installed on 24 June 1784 on the right front framework (see Table 2-13).

296 Both metric and non-metric units are used in this book, depending on the context.

297 The exact value is 15' 3", measured by the passage of an equatorial star.

298 The ladder angle γ is due to Caroline, noting for PD 103° that “the tube is perpendicular to the ladder” (RAS W.2/7: 32).

299 On 15 March 1784 (sweep 217), the focuser was installed at the upper 45° position: “This evening I used the first time my eye glass placed on the slant side of the octagon tube. I find it more commodious for the eye, since the natural position is rather downwards than strait on. I can also follow the perpendicular motion of sweeping better by stooping a little

when the telescope goes down."

300 See the letter of William Watson Jr to Herschel of 9 November 1783, RAS W.1/13: W.29.

301 Bennett (1976a). See also Caroline's manual, written for a 20-ft reflector with a 12-inch mirror sent to St. Petersburg in 1803 (RAS W.5/9). The telescope was never used at its destination; see Maurer et al. (2016).

302 Occasionally, when observing special objects (planets, showpieces for visitors), the telescope was turned to the required azimuth by the 'round motion' (it made no sense to wait for their meridian passage). The motion was also needed in autumn 1784 to perform the eastern sweeps (azimuth 90°) and later for the many northern sweeps (azimuth 0°).

303 Herschel Mrs. J. (1876: 53).

304 This report is a bit more detailed than *Journal No. 7*; see RAS W.2/1.5: 48 and RAS W.2/1.7: 15.

305 Herschel W. (1786a).

306 Herschel Mrs. J. (1876: 136–137); the crash happened on 17 March 1784.

307 Such star groups are not clusters; their pattern appears by chance. The term 'asterism' is also used.

308 RAS W.4/1.5: 453. The open cluster Stock 8, studied 1956 by the German astronomer Jürgen Stock (1923–2004), may appear nebulous under very good conditions. The surrounding emission nebula is IC 417, found 1892 on a plate by Max Wolf (1863–1932), Director of Königstuhl Observatory (he discovered 1113 IC objects). Herschel returned to the area in sweep 1030 (4 February 1793) but missed the cluster, so it is not listed in the NGC. Naked-eye views of M 13 (1799, 1805), M 15 (1799) and M 35 (1794) are mentioned in Herschel W. (1818: chapter II).

309 However, ι Ori is not a double star. Herschel had found three telescopic pairs to the north in 1779, listed as III 12–14.

310 For the supposed comets found by William and Caroline, see Table 3-2.

311 On 27 October 1785 (sweep 467), Herschel discovered a celestial 'companion' of NGC 253, the globular cluster NGC 288 (VI 20). The low concentrated 8.1 mag object lies 1.8' southeast of the famous Sculptor Galaxy.

312 The nebular 'trio' was again observed in sweep 296 (16 October 1784).

313 Herschel noted: "It appears with it like a well defined sharp small billiard ball. My speculum as yet is not perfect so that there was a double image but the brighter of the two was better than any I have ever seen in any one of my instruments. I observed it for a good while during its Meridian passage." (RAS W.2/3.2: 68).

314 Uranus was observed in 1784 on 18 January and 16 November and in 1785 on 29 January, 13 & 28 February and 7 December. Herschel planned the sweeps in Gemini to encounter the planet. In his discovery

account on the two moons (sweep 683, 11 January 1787), he wrote: "I selected a sweep which led to the Georgian planet." See Herschel W. (1787).

315 Later, in sweep 403 (27 April 1785), Herschel analysed the light of the red giant α Boo: "I saw Arcturus in the meridian through the 20ft with the sweeping power and prism. It gave a beautiful spectrum with all the colours very visible. The red however seemed very full." See Hoskin (2006) for Herschel's 'prismatic experiments'.

316 Although NGC 2420 is Herschel's first open cluster found in a sweep, it was not his first such discovery. He had already found eight exemplars in the star reviews.

317 RAS W.5/9: 3.

318 Herschel W. (1795b: Fig 39).

319 RAS W.5/12.1: 5. On 7 September 1784 (sweep 259), the method was tried on the Veil Nebula V 15 (NGC 6960) in Cygnus. In sweep 609 (13 October 1786), Herschel finally changed to a front-view design with a tilted main mirror, removed secondary mirror and a much more stable observing platform, installed at the front of the telescope (see section 2.5.4). This avoided loss of light caused by imperfect reflection by the secondary mirror.

320 Lemaire (1732). Jacques Lemaire (1676–1746), French optician, working in Paris. Already in 1616, the Italian Jesuit-astronomer Niccolò Zucchi (1586–1670) had experimented with a tilted concave mirror and a concave eye-piece lens in the front. The image showed too much aberration; King (1979: 44), Watson (2004: 109).

321 The identity of 'Collins' is unknown.

322 The uncatalogued clusters of sweep 35 (3 December 1783) were later found again, not mentioning the early observation. NGC 2432 is VI 36 of sweep 934 (4 March 1790) and NGC 2421 is VII 67 of sweep 1089 (30 January 1799).

323 Herschel wrote a paper on his Mars observations, made since 1777; it was finished on 1 December; Herschel W. (1784a).

324 The classic transit instrument is the 'meridian circle', used to measure accurate star positions.

325 RAS W.4/1.5: 467.

326 Herschel W. (1786a: 459-460).

327 The finder, installed near the eye-piece (Newtonian focus), had a 2¾-inch lens and 2° field of view with crosswires.

328 Of course, a bright star in the field also caused a loss of adaptation (Table 5-4). In sweep 156 (23 February 1784), Herschel saw Procyon: "The light of this star was so very glorious that I could not without injury keep my eye close to the tube so as to take its passage exactly." In sweep 170 (14 March 1784), he encountered the even brighter Arcturus: "too bright to keep the eye at the telescope without having injury after having

been so long in the dark". When NGC 5490 (III 32) was found on 8 April 1788, although the star was 2° northeast it still caused much stray light: "Arcturus being too bright".

329 However, Lubbock (1933: 146) wrote in the chapter, covering the years 1782–86: "At the bottom of the erection [telescope framework] were two small rooms, one for Miss Herschel to write down the observations as they were made by her brother, the other for the man who assisted in the movements required." This quote is from the journal of Charlotte Papendiek (1762–1840), a lady-in-waiting of Queen Charlotte. It does not describe the 20-ft, but the 40-ft!

330 The 40-ft was equipped with a speaking pipe to transfer the information from the gallery to the hut at the tube end.

331 Herschel W. (1786a: 460).

332 Herschel twice writes that '45' sweeps were made 'in the parallel'. The correct number is 41 (a systematic error).

333 In the case of the *Journal*, this concerns only sweep reports.

334 If there are more pages of *Fixt Stars No. 7*, they were not archived. The possibility of additional pages is supported by Caroline's *Sweeps* series. Here the 'stroke with a pen' (marking a copy) ends with sweep 259 (7 September 1784). Thus, about 50 pages are missing.

335 Herschel still continued his *Journal*, but now containing observations of Solar System objects only.

336 This is the only document mentioning Herschel's additional sweep 1113, made on 31 May 1813, about 11 years after the great campaign.

337 It is equivalent to the Messier number, assigned in the same manner.

338 See Table 5-1 for more documents.

339 There were no observations of Mars and Venus with the 20-ft reflector. Though, it was possible to see Mars in a sweep, the planet was never in a sweep area. This is excluded for Venus, because it crosses the meridian only in daytime.

340 Caroline names the *Journal* as the '2nd copy' of the sweeps (RAS W.2/3.3: sweep 290); the *Sweeps* series is the 'Original'.

341 See Caroline's introduction in RAS W.2/3.1.

342 Non-stellar objects: RS MS/339–43; Messier objects: RS MS/344; double stars: RAS W.2/5.1–4; compare Table 5-1.

343 William James Herschel (1833–1917), the third of John Herschel's 12 children (see Introduction, page 3).

344 Dreyer (1918a). In 1978 the Herschel Archive was again reviewed by Bennett (1978). The content was later digitized and is available on three DVDs. Alas, the documents archived at the *Royal Society* are still not digitized.

345 Below the record of sweep 46 in *Sweeps No. 1*, Caroline wrote: "The original delineations of figures for determining the place of nebulae are in the Journal Nr. 7, expect that of the next page [sweep 47]." There, finder

views show a crosshair, telescope views not.

346 In Herschel W. (1786a: notes) we read: “This has been a telescopic comet, as I have not been able to find it again, notwithstanding the assistance of a drawing which represents the telescopic stars in its neighbourhood.” Alas, there was no comet in the area at the time.

347 The definition of Herschel’s eight classes is given in Table 2-32.

348 The galaxies are 42' apart, which is about three fields of view.

349 Moonrise was at 2:30 am in Virgo.

350 Herschel J. (1833a).

351 Dreyer inserted the object in his revised version of the first Herschel catalogue, Dreyer (1912a: 292).

352 In sweep 55, the ‘unknown star’ U^2 was found in Orion. Caroline’s final list contains 1117 ‘unknown stars’ (RAS C.3/2.3).

353 The accuracy of the method was sufficient enough to identify a new object. Sometimes up to three finder views were sketched to demonstrate the situation.

354 The galaxy disk is seen from above; the other extreme is the side view, called ‘edge-on’.

355 It is documented that an eye-piece holder was used in the front-view design, see Dreyer (1912a: xlii, note).

356 While observing an “exceedingly faint, not small” nebula in Leo with different powers, Herschel noted on 8 April 1784 (sweep 187): “I had some doubts and therefore put on 240 but as there was not a star near I could not adjust the focus, which cannot be done on a nebula therefore as it would have taken too much time to verify it I went on.” However, there is nothing at the place. Nevertheless, the ‘object’ was catalogued as III 75 (NGC 3498). The remark about the ‘star gage’ comes from sweep 238 (15 July 1784).

357 RAS W.5/9: 10. Dreyer (1912: xl, note) assumed about the fact that every star could pass three times: “This can only refer to a sliding eye-piece, as the telescope was certainly only moved in P.D. during the sweeping.” This is incorrect.

358 There was already a ‘sweep 67’ on 24 December, but due to haziness it was not registered.

359 See also Table 2-26, Figure 2-92.

360 The variation was first reported by the eminent American astronomer Edwin Hubble (1889–1953) in 1917.

361 In his journals, Herschel usually tells us which time (ST or GMT) is meant for a certain observation. If not, the format should be clear from the context.

362 Herschel W. (1786a: 460).

363 Of course, Flamsteed’s *British Catalogue* itself is not free from errors, like incorrect positions. A revision was published by Baily (1835).

364 Herschel followed Flamsteed in using PD (also called NPD = ‘north

polar distance') instead of declination. We have PD = 90° - δ. However, Herschel gives AR in hours (instead of degrees).

365 As we have seen, Herschel numbered the stars in each constellation.

366 Herschel Mrs. J. (1876: 61).

367 RAS C.2/1.3. Don't confuse the zone catalogue of Flamsteed stars with her later *Zone Catalogue* of non-stellar objects.

368 RAS C.2/1.1.

369 See 6.3 for the position accuracy.

370 Again, this clear cold night was long and exhausting for the Herschels. Over 8.3 hours, nine sweeps were made (67–75) with a total observing time of six hours.

371 RAS W.4/33.6 (item 3): 1.

372 Mitchell (1767).

373 The nine discoveries are: NGC 457, NGC 1980, NGC 1981, NGC 2129, NGC 2169, NGC 2281, NGC 6535, NGC 6802 and NGC 6871. The rest (M 8, M 47, M 79) were found earlier.

374 NGC 3853 (sweep 72), found above β Leo, was not catalogued by Herschel: "I saw a small nebula but in looking a good while at the finder to determine its place lost it again in the telescope; and I would not stop long to interrupt the sweep, I suspect partly that it only consisted of a few very small stars, but shall look for it another night." The place could be reconstructed and the object identified.

375 RAS W.4/33.6 (item 3): 7.

376 The pair was observed again on 11 March 1784 (sweep 164). It is curious that M 95 was 'discovered' eight days later in sweep 177 (19 March). Herschel did not recognize the identity and catalogued the bright galaxy as I 26. Both galaxies were again seen in sweep 188 (12 April) – and correctly designated. However, sweep 177 is not mentioned!

377 Herschel Mrs. J. (1876: 55). Strong frost also influenced observations at elevations above 70°. The 20-ft acted not well.

378 Guiseppe Piazzi (1746–1826), Italian astronomer, Director of Palermo Observatory. The date of his injury is not known, but it could have happened on 3 November 1787 (sweeps 773 & 774), 6 August 1788 (visit together with Pigott and Oriani) or 13 December 1788 (sweeps 889–91); the sweeps were made in the north above the pole (high elevation).

379 This and the following annual summaries, concern the sweep period 1783–1802. For earlier events see the Timeline in the appendix.

380 Hoskin assumes a date lying between "the second half of 1784 or the first half of 1785"; Hoskin (2011a: Plate 2).

381 The Rev. Thomas Rackett (1755–1840), English clergyman and antiquarian.

382 In the period of the chair (January 1784 – September 1786), the maximum range of its vertical position, adjusted to look into the eye-piece, was about 12 inches; the value depending on the tube elevation

and sweep breath (max. 3.1°).
383 RAS W.5/9: 3. The ‘lateral motion’ is no longer mentioned.
384 Herschel W. (1814: Fig. 14).
385 Herschel had found 42 objects (one more than Messier). However, as already mentioned, he must have believed that the French astronomer discovered 62 objects. By Caroline’s count, this number was exceeded on 24 January (sweep 122), when the galaxy NGC 4772 (II 24) was found in Virgo.
386 However, until now only IV 1 = NGC 7009 is a planetary nebula (PN) in the modern sense. Indeed, IV 2 to IV 10 are of different type (emission/reflection nebula or galaxy). Herschel’s next true PN was IV 11 = NGC 6369 in Ophiuchus, discovered in sweep 222 (21 May 1784); see Table 2-53.
387 Herschel adds that 15 Mon “is itself a double star of the 3rd class […] there is also another double star of the 3rd class not far from it”. Neither pair was catalogued.
388 The variability of the 5.8 mag star was not detected by Herschel.
389 Herschel J. (1864), Dreyer (1888).
390 RAS W.4/1.6: 498, RAS W.2/3.1.
391 See Table 2-7. In the revised sweeps a “considerable star, not in Fl” was used, found in sweep 103. It was entered as O170 in Caroline’s ‘Catalogue of omitted stars’, listing stars observed by Flamsteed, but not inserted in the *British Catalogue* (RAS C.2/4.2). Later the star was identified in Bode’s catalogue of 1801; it is located in Leo, about $1^h\ 16^m$ west of the nebula.
392 RAS W.2/1.7: 42 (left page).
393 M 61 is also a problematic case, see 2.5.2.
394 RAS W.1/1: 242.
395 RAS W.2/7.
396 NGC 4470 is not in the *Zone Catalogue*. Lord Rosse saw NGC 4467 and NGC 4470 on 26 February 1851 (“4 found”). The other two are M 49 and 12.6 mag galaxy NGC 4492, 18' northeast of the Messier object. This is Williaml’s II 499, found in sweep 498. John entered the three ‘new’ Rosse nebulae as GC 3022–24 (h 1294, a) in the *General Catalogue*.
397 Dreyer (1912a: 295).
398 RAS W.2/5.1: entry “2 Nr. 38”.
399 Herschel W. (1786a: 461).
400 The installation of the PD string might be a consequence of the position disaster, happening the night before (see section 2.2.1). Of course, the device had to be removed when the telescope was turned azimuthally by the ‘round motion’.
401 The other is NGC 6412 (VI 41), a 11.8 mag galaxy in Draco.
402 Occasionally, the limit was exceeded by several arcminutes to reach a known star.
403 Herschel W. (1795b: Fig. 44 & 45).

404 On 21 April 1784 (sweep 207), Herschel noted: “51 (θ) Virginis transit the wire of the finder, but the adjustment is not very accurate.”
405 Herschel W. (1814: Fig. 16).
406 On 22 February (sweep 155), Herschel wrote: “My new object speculum is very perfect both in polish and figure, a few scratches excepted.”
407 If a and b are the large and small diameters of the ellipse, enclosing the edge-on galaxy, the axis ratio is defined as a/b.
408 The abbreviations n, s, p, f and combinations like nf or sp were commonly used by visual observers in the 18th and 19th century to describe sky directions (like in the field of view); p and f are defined by the sky motion. We have: n = north, s = south, p = preceding (west), f = following (east), sp = south preceding (southwest), nf = north following (northeast).
409 This is one of the seven additional Messier objects (M 104–110); see Table 5-9.
410 Herschel W. (1784b: Table XVII); the selection is partly based on a compilation of 10 sketches in *Journal No. 8*. RAS W.2/1.8: 1; Herschel gives a comment for only a few objects, Herschel W. (1786a).
411 Although the Siamese Twins appear to be physically connected, the overlap is only an optical effect in the line of sight. NGC 4567/68 is the only case where Herschel put two neighbouring objects in class IV (‘planetary nebulae’).
412 Steinicke (2010d).
413 Shapley, Sawyer (1927). Harlow Shapley (1885–1972), American astronomer, working at Harvard College Observatory and on Mt. Palomar. Helen Sawyer (1905–1993), later ‘Sawyer-Hogg’, was Shapley’s assistant.
414 Alexander Gordon, 4th Duke of Gordon (1743–1827); among the other guests was James Lind.
415 Steinicke (2010a: 286).
416 When John observed II 80 on 25 March 1827, he wrote: “Query if not bicentral”. Curiously, he believed to have seen II 48 as well: “The faintest object imaginable, and discerned with the upmost difficulty.” Indeed, there is a galaxy at William’s position, NGC 2677, but with 14.6 mag, this cannot be the ‘pretty bright’ nebula II 48.
417 Of course, an object which was already seen can be followed by the ‘side motion’. But this case is different. See section 5.1 for a detailed discussion of the sweep method.
418 All of March 1784 was very windy. On the 14th, Herschel noted that “the agitation from the wind was so violent now and then that I was obliged to hold and guide the telescope”. An on the 27th: “The whole sweep extremely windy, the tube ill adjusted & circumstances not favourable, though the air was clear enough.”
419 Dreyer catalogued I 26 as a new object, NGC 3345, writing “eeF (if

anything)". He corrected his error in the *Scientific Papers*; see Dreyer (1912a: 295).

420 Eye-piece No. 4 gives 240×. On 11 March (sweep 164), Herschel wrote: "the focus of that glass is exactly 1 inch".

421 NGC 3474 is credited to the American astronomer Lewis Swift (1820–1913). He discovered 446 NGC- and 442 IC objects.

422 In the first half of 1784, five double stars were discovered in the sweeps, designated as N1 to N5.

423 RAS W.4/23. Some sentences are missing at the beginning.

424 Herschel W. (1784b).

425 "Coma itself" means the large Coma Berenices Cluster, stretching over 4° in the north-eastern part of the constellation. The open cluster, catalogued as Mel 111, is easily visible to the naked eye. Except for Herschel's casual mention, there is no report of an observation. However, on 1 January 1783, he found a double star inside the cluster, V 121 (12 Com).

426 Messier (1781). Messier's famous star charts of selected sky regions were reprinted in 2018 by Albireo-Verlag, Köln.

427 Because the was no specific target, the observer change at the chair of the 20-ft was no problem.

428 NGC 5466 is among the globular clusters with the highest (absolute) galactic latitude. NGC 288 in Sculptor (-89°) holds the record, followed by NGC 5053 (+79°) and NGC 4152 (+77°), both in Coma Berenices, and NGC 5466 in Boötes (+74°).

429 Steinicke (2014b).

430 Globular clusters are among to the oldest Milky Way objects; they mainly contain aged red stars of low mass.

431 B 86 refers to the catalogue of 'dark nebulae' of Barnard (1919). The American astronomer Edward E. Barnard (1857–1923) had found the small object in 1883. In 1913 he wrote: "It is a very striking object in a 5-inch telescope, where it looks like a drop of ink on a luminous sky." See Steinicke (2016c, 2016e). Barnard discovered 17 NGC- and 146 IC objects.

432 The chain was first described by the Armenian astronomer Benjamin Markarian (1913–1985).

433 M 87, the dominant Virgo Cluster galaxy, was seen on the 12 April (sweep 189). NGC 4402 found by Johnstone Stoney (1826–1911) in 1849 at Birr Castle. He discovered 50 NGC objects.

434 Steinicke (2014c). This point was already remarked by Dreyer (1212a: liii). A modern 14-inch reflector shows the spiral pattern of M 51 and M 99 under good conditions. This demonstrates that it is generally easier to perceive a known structure.

435 Herschel W. (1811: Fig. 29).

436 The relevant quantity is the 'inclination' (i) of the spiral galaxy, defined

as the angle between the (rotation) axis of the disk and the line of sight; i = 0° means face-on, i = 90° edge-on. For instance, M 65 and M 31 show an inclination of about 70°, making it rather difficult to see spiral arms.

437 Messier determined the M 91 position from M 89, thinking the latter was M 58.

438 Steinicke (2019a). M 104 was added 1917 by the French astronomer Camille Flammarion (1842–1925); M 105–107 in 1947 by the Helen Sawyer-Hogg; M 108 and M 109 in 1954 by the Harvard astronomer Owen Gingerich (*1930). Finally, Kenneth Glyn Jones added M 110 in 1967.

439 M 64 was first seen with the 20-ft on 13 April 1785 in sweep 398.

440 John Bird (1709–1776), British instrument maker. The 18-inch quadrant was equipped with a bubble (spirit level) for the horizontal adjustment. Herschel later recognized that the adjustment was defective by +17'.

441 Herschel W. (1786a).

442 The galaxy plays a role in the 1814 paper, discussed in section 4.2.2; Herschel W. (1814).

443 Herschel W. (1811: Fig. 32).

444 NGC 3489 is shown in Herschel W. (1814: Fig. 11), NGC 4262 in Herschel W. (1811: Fig. 40).

445 There is also a star group and two pairs; three objects could not be verified. Except for one (II 118), all are in the NGC.

446 John Herschel's popular book *Outlines of Astronomy* presents six 'annular nebulae' for both hemispheres; Herschel J. (1869, Vol. II: 792). The northern exemplars are M 57, NGC 3242, NGC 6369 and M 94. Why the galaxy M 94? The spiral arms of the galaxy are wound up to a ring, which causes the 'annular' appearance; a similar case is NGC 4750 (IV 78) in Draco, see Figure 3-19.

447 John coined the name: "The figure of this nebula is nearly that of a Greek capital omega Ω."; Herschel J. (1833a: 498).

448 Among the double stars are 5 Aql (N9), 57 Peg (N16) and ρ Ori (N21). The garnet stars are RT Cap (sweep 246), ε Cyg (258) and BL Ori (293); see Table 2-11.

449 This was done in the period of the eastern sweeps (October 1784).

450 Barthélemy Faujas de Saint-Font (1741–1819) was a French geologist; for his visit at Datchet see Faujas (1799), Dollfus (1987), Ashworth (2003), Hoskin (2014a: 87).

451 Ashworth (2003).

452 Even Lord Rosse could not resolve the globular cluster with the 72-inch reflector in 1850.

453 There are seven observations of M 31 with the 7-ft, made between August 1780 and August 1783.

454 NGC 206 is a large stellar system inside M 31, made of young luminous

stars; such an object is called a 'super star cluster'.

455 However, the credit goes to Messier (10 August 1773).

456 M 31 and its vicinity was again observed in the regular sweeps 613 and 618 (17 & 18 October 1786). Now NGC 206 was catalogued as 'large nebula' V 36. Since I 54 turned out to be M 32, the designation was later used for a different object: the galaxy NGC 393 in Andromeda, found on 18 October 1786 (sweep 618) and located 5° southeast of M 31.

457 After sweeping on 20 December 1784, Herschel viewed NGC 7662 with the 7-ft: "The planetary nebula near the 13th Andromeda with 278 very ill defined & faint."

458 See Steinicke (2006b).

459 The prominent variable star was monitored by Herschel from 27 April 1783 to 8 October 1804 (see Table 1-16).

460 Herschel W. (1811: Fig. 33).

461 Beside NGC 29 and NGC 7662, three other planetaries were discovered: NGC 6772 (IV 14) in Aquila, NGC 6894 (IV 13) in Cygnus, which is less than 1' in diameter, and the Blue Flash Nebula NGC 6905 (IV 16) in Delphinus (see below).

462 This was the highest meridian position so far: declination +36°, PD 54°, elevation 74°.

463 The globular cluster is also catalogued as Palomar 9, found in 1952 by the American astronomer George Abell (1927–1983) on the *Palomar Observatory Sky Survey* (POSS).

464 The document 'Planetary Nebulae pointed out by Stars' treats 17 objects (RAS W.4/33.4). Finding charts for 10 Messier objects are also presented.

465 There is another member of the group, catalogued by Dreyer as NGC 2183. The reflection nebula was found by Bindon Stoney (1829–1909) in 1850 at Birr Castle. He discovered 90 NGC- and six IC objects.

466 Koch (1800).

467 ε Cyg is very similar to Mira in Cetus. Both show a long period and red colour. Actually, these are red giants, i.e. large, massive stars in their final stage of stellar evolution. See Table 2-11 for Herschel's 'garnet stars' found during the sweep campaign.

468 Herschel W. (1786a). He gives a wrong discovery date for NGC 6992 (5 September), not noticed by Dreyer (1912a: 289). The error found its way into the literature; see, for instance, Bratton (2011: 211).

469 Herschel W. (1811: Plate IV, Fig. 1).

470 With a modern wide-field telescope, faint, large nebulae are easy targets. Often a filter can be useful; Steinicke (2019c).

471 Dreyer (1912a: xlii, last footnote); see Steinicke (2017c).

472 Comparing and Figure 2-70, William must have seen NGC 6995 as a part of NGC 6992.

473 Truman Safford (1836–1901), was an American astronomer and

Director of Dearborn Observatory, Evanston. He discovered 29 NGC- and 39 IC objects.

474 Lawrence Parsons, 4th Earl of Rosse (1840–1908); Lord Rosse's son and successor at Birr Castle discovered 36 NGC objects.

475 Of course, it should be called 'Fleming's Triangular Wisp'. Williamina Fleming (1857–1911), American astronomer, working at Harvard College Observatory. She discovered 45 IC objects.

476 There are three further companions: NGC 7336, NGC 7337 and NGC 7340. They were discovered by the Birr Castle astronomer Johnstone Stoney in 1849.

477 Steinicke (2014a).

478 Herschel's observing chair must be moved vertically by about 30 cm (12 inches).

479 NGC 379 is entry no. 500 in Caroline's final counting (used for the first catalogue).

480 If Herschel had used the eye-piece No. 4 (240 ×), a separation might be successful. The pair was eventually resolved in 1850 by Bindon Stoney with the 72-inch reflector at Birr Castle.

481 A similar case is NGC 4782/83 (I 135/36) in Corvus, discovered on 27 March 1786 in sweep 548.

482 Again, it was Bindon Stoney who resolved the double galaxy in 1850 at Birr Castle. Herschel might have been successful with 240 ×. His closest pair was NGC 545/47 in Cetus (30" apart), discovered on 1 October 185 (sweep 448); Figure 2-101.

483 Dreyer credits NGC 7770 to Lord Rosse; actually, Bindon Stoney had seen it in 1850. He was also beaten by John Herschel, who saw the nebula on 25 August 1827, but hadn't catalogued it.

484 Steinicke (2010c).

485 If a spiral galaxy is seen edge-on, the term 'flat' is additionally used, if the disk is very thin. The most extreme case is called 'superthin galaxy'.

486 Herschel W. (1785c: 260).

487 There were even seven observations, made between 1794 and 1810 with 7-ft and 10-ft; nothing is said about V 17.

488 This is a compact Newtonian reflector of 24 inches aperture and 10 feet focal length, built in 1799. The focal ratio of 1:5 gives a great light gathering power (see section 3.2.2).

489 There are two other observations with the X-foot: 9 December 1805 and 4 December 1810. Nothing new was seen.

490 The modern term 'HII-region' refers to a cloud of ionized hydrogen. NGC 2903 was Lord Rosse's second spiral galaxy (after M 51); his drawing also shows NGC 2905.

491 Two minutes later and 1.5° south, he saw another large nebula, M 8. This is a different and even more complex story, told below.

492 Glyn Jones' translation is incorrect in writing "Star cluster near M 20:

the brightest star is 11 Sagittarii, 7 mag." See Glyn Jones (1991: 105). This would imply a different position, about 2° southeast. It is interesting that Messier has counted the Flamsteed stars, like Herschel has done later.

493 Herschel J. (1847: Fig. II.2).

494 The name is due to the Irish-British astronomer and author Agnes Mary Clerke (1842–1907); see Clerke (1890); Herschel J. (1847: Fig. II.2).

495 Herschel W. (1785c: 261).

496 In the record we later read that the sweep was interrupted "about 3 or 4' [minutes] for viewing Saturn".

497 Ptolemy's Cluster M 7, another 2.5° lower, was never observed with the large reflector.

498 The open cluster M 16 is embedded in a nebula, found visually by the French astronomer Étienne Trouvelot (1827–1895) in 1876 at the 26-inch refractor of U.S. Naval Observatory. Dreyer catalogued the object, coined Eagle Nebula, as IC 4703; see Steinicke (2009b). The nebula is often mistakenly called M 16 by the uninformed.

499 RAS W.2/2.8: 3.

500 The visitor was the politician Henry Temple (1739–1802), second Viscount of Palmerston. James Lind was also present.

501 First, Lord Rosse supported this impression, later he changed his mind, whereas Romney Robinson still believed that all nebulae are disguised clusters (his claim was based on pure ideological reasons). The subjectivity problem of visual observing is still present today; Steinicke (2012d, 2014c).

502 The night also brought the planetary nebula NGC 6772 (IV 13) in Aquila. The 12.7 mag object was seen "nearly of equal light throughout in the midst of numberless stars of the milky way".

503 John, not aware about his father's observation, wrote on 22 February 1830 (sweep 298): "A fine ruby star. Pure ruby colour. This is perhaps the finest of my 'ruby stars'." Herschel J. (1847: 449).

504 Johnstone Stoney's sketch of 13 December 1848 at the 72-inch shows the spiral structure; see Parsons L. (1880: 21).

505 The "gaging power of 14" refers to Herschel's formula for the 'space-penetrating power' of a telescope (see section 3.3.1).

506 The Merope Nebula was found in 1859 by the German astronomer and lithographer Wilhelm Tempel (1821–1889); he is credited for 149 NGC- and one IC object. Maia is also involved in faint nebulosity (NGC 1432), detected on a plate in 1885; Steinicke (2010a: chapter 6.17). This is worth mentioning, because Herschel claimed to have perceived a large faint nebula around ε Ori on 1 February 1786 (sweep 518); the non-existent object was catalogued as V 34 (NGC 1990).

507 Only 35' west of NGC 2158 is a third open cluster, IC 2157, found in 1899 by the British astronomer Thomas Espin (1858–1934); he

discovered 18 IC objects. M 35, NGC 2158 and IC 2157 built a remarkable chain of 1° length.

508 The other object is the cluster NGC 2627 (VII 63) of sweep 1032 (3 March 1793); reference star '19 Pixidis of Bode's Cat.'

509 The telescope must have been turned by the 'round motion' after the sweep.

510 RAS W.7/8.

511 Herschel W. (1785a). The story is told in Owen Gingerich (1984).

512 RAS W.4/24.

513 Herschel W. (1785c: 213-266). The publication shows two added notes below the text, mentioning observations of nebulae made on 1 and 7 February.

514 Later in the paper, Herschel explicitly speaks of a 'globular cluster of stars'; Herschel W. (1785c: 226).

515 See Hoskin (2012a: 52); Fig. 3.8 is made by the author.

516 There are only seven Herschel objects within 10° of the SGP. The closest is the globular cluster NGC 288 in Sculptor, located 36' northeast of the celestial point; all others are galaxies: NGC 24, NGC 171, NGC 216, NGC 247, NGC 253 (Caroline's nebula) and NGC 613.

517 There is no source for these observations. Maybe it is a mix of several M 31/NGC 205 observations, made before 1785.

518 Clerke (1895: 112).

519 RAS W.2/2.5: 53.

520 Steinicke (2010a: chapter 2.7). Friedrich v. Hahn (1742–1805) was a German astronomer, who built a private observatory at Remplin Castle in Mecklenburg-Vorpommern. Later, John called M 57 an 'annular nebula'.

521 For planetary nebulae in the modern sense, see Table 2-53.

522 See Steinicke (2007b).

523 The night was very cold (-10°C) and wet: "changed the small speculum, the other much affected by damp".

524 See Herschel W. (1811: Fig. 31) and Herschel W. (1811: Fig. 9) for NGC 936 and NGC 2974, respectively.

525 Alas, the Horsehead Nebula, the famous dark region (IC 434) only 15' southwest of NGC 2023, was never seen.

526 Jean Hyacinthe de Magellan (1723–1790) was a Portuguese natural philosopher, who had settled in London.

527 The text is a letter to Bode; see Bode (1785a: 162–64); Hoskin (2014a: 91).

528 Herschel W. (1814: Fig. 21).

529 NGC 450, lying at a distance of 65 million light-years, superimposes UGC 807 at 525 million light-years. UGC refers to the *Upsala General Catalogue* (of galaxies).

530 In Caroline's table of reference stars (RAS C.3/2.3) we read in Zone 63 "Star or &c. obs. forgot." However, near the place about 1° northwest of υ

Gem is a remarkable asterism (chain of six stars).

531 The visual brightness of R Lep varies between 5.5 and 11.7 mag in a period of 427 days. The colour index is 5.8. Obviously, Herschel has seen the star about minimum brightness.

532 The star is variable (TX Psc) and has a colour index of 2.6.

533 The name was coined by the astronomer Captain William Noble (1882–1904), first President of the *British Astronomical Association*, writing in 1886: "a pale blue disk, looking just like the ghost of Jupiter".

534 The visitors were William Watson Jr and the Irish orientalist William Marsden (1754–1836).

535 Steinicke (2009a).

536 Steinicke (2012a).

537 Herschel W. (1811: Fig. 18).

538 A "faint red colour visible" was also noted for the emission nebula NGC 2467 (IV 22) in Puppis, observed on 6 March (sweep 381). The bright galaxy NGC 772 (I 112) in Aries, discovered on 29 November (sweep 481) showed the same: "a faint red colour perceivable". It is unknown what caused the phenomenon.

539 Later the 20-ft often operated in the north to find pole-near objects (PD $\leq$ 38.5°). The 'PD string' had to be removed.

540 Moonset was at 10:38 pm, moonrise at 5:32 am (phase = 0.14); see the analysis of sweep 396 in 5.1.2.

541 John observed the galaxy on 27 February 1827 (h 694): "So extremely faint that I remained unsatisfied." With a diameter of only 0.3', NGC 3196 is William's smallest galaxy (together with NGC 742, found on 13 December 1784 in sweep 338).

542 MCG refers to the *Morphological Catalogue of Galaxies*.

543 In 1958, George Abell catalogued 2712 rich clusters of galaxies, found on the *Palomar Observatory Sky Survey* (POSS).

544 Four members were found by John in 1827 and 1831.

545 'Star gages' usually were performed, when Herschel saw no risk of losing a new object.

546 It is catalogued HCG 61; one of the 100 compact groups of galaxies, compiled in 1982 by the British-Canadian astronomer Paul Hickson (*1950).

547 In 1913, Max Wolf found the six HII-regions on a plate; Dreyer catalogued them as IC 3550–52, 3555, 3563 and 3564.

548 Steinicke (2005).

549 In sweep 387 (13 March), Herschel found NGC 4966 (III 304) and sweep 393 (6 April) brought NGC 4789 (II 345) and NGC 4819 (II 346); the latter was seen again in the monster sweep 396. The 12.1 mag galaxy NGC 4789 in Coma Berenices is only 38' away from the North Galactic Pole.

550 Stopping a star gage already happened on 8 February (sweep 371):

"The following nebula was in the field of this gage […] A star with an exceeding faint brush towards the preceding side, or a very faint nebula close to and preceding the star. I perceived it in stopping the gage, otherwise should certainly have overlooked it. 240 shewed the same." The object is NGC 3456 (IV 29), a 12.6 mag galaxy in Crater; a 13th mag star is 30" northeast; see Table 2-26 and Figure 2-92.

551 The name is due to the strong interaction, forming two long tails of stars and matter, pointing in opposite directions.

552 Lord Rosse has detected the spiral structure on 18 April 1855. Three other face-on galaxies were found by Herschel in 1785: NGC 3344 (I 81) in Leo Minor, NGC 5068 (II 312) and NGC 5247 (II 297) in Virgo. The former was seen as 'spiral' on 27 January 1852 at Birr Castle.

553 NGC 3821 was – in Caroline's final count – Herschel's 1000th discovery, the magical number of the first published catalogue (see section 2.4.1).

554 The galaxies are all members of an extended galaxy cluster, described by the eccentric Swiss astronomer Fritz Zwicky (1889–1974). NGC 4069 (15.2 mag) is among Herschel's faintest objects.

555 Table 5-5 collects all objects, not catalogued by Herschel.

556 Six IC objects would follow in the sweep campaign (see Table 3-3). However, only one was catalogued: IC 3668 (I 179), discovered on 9 April 1787 in sweep 725.

557 Herschel W. (1811: Fig. 25).

558 Also, the English physician and scientist William Watson Sr (1715–1787), father of Herschel's friend William Watson Jr, had urged in a letter for a change of residence; Herschel Mrs. J. (1876: 140).

559 See Hoskin (2011a: 112).

560 John Shelton (1712–1777) was a famous London clockmaker. He made five 'astronomical regulators' for the *Royal Society* used during the Venus transits of 1761 and 1769.

561 The galaxies are NGC 6959, NGC 6961, NGC 6965 and NGC 6967. There were discovered at Birr Castle in 1857.

562 Bode (1801a, b). The equinox is 1 January 1801.

563 RAS W.2/3.1: 2. She noted: "Above 8,760 observations have been brought to 1800." Herschel Mrs. J. (1876: 109).

564 Wollaston (1789). Francis Wollaston (1731–1815), was an English astronomer and priest of the Church of England.

565 The number '800' is curious, because there are 1885 objects in the omitted classes II & III, leaving 615 for the rest.

566 RAS C.4/3: 18. Caroline's note is dated "March 7, 1834 a memorable day". It was John's 42nd birthday, the first he must celebrate far from home (private communication by Woody Sullivan and Emily Winterburn).

567 RAS C.3/8.

568 Baily (1835: 562, note 1240). Later, the error was independently noticed by Auwers.

569 RAS C.4/3: 18.

570 Bode (1777, 1782). Possibly William possessed Bode's atlas and catalogue of 1782. On 4 August 1786, Caroline wrote a letter to Dietrich in Hanover about the discovery of her 1st comet; he should observe the object. The place was described by Flamsteed stars, writing: "All stars of Flamst. are in Bode's Cat. to be found." Herschel Mrs. J. (1876: 71).

571 Bode (1788, 1791, 1804a, b). The Berlin astronomer also published unauthorized German versions of Herschel's papers; William was not always amused.

572 Bode (1801a, b). The positions are for 1801. The catalogue contains objects form the *Messier Catalogue* and Herschel's first and second catalogue; the third appeared later and was published by Bode not until 1804.

573 d'Arrest (1856); Auwers (1862).

574 Other members were already found on 18 and 21 October 1784 (sweeps 297 & 305), NGC 7648 (III 218) and NGC 7671 (III 226) and on 25 October (sweep 464), NGC 7562 (II 467).

575 14 members of the galaxy cluster Abell 194 in Cetus bear NGC-numbers.

576 John Smeaton (1724–1792) was a British civil engineer and a good friend of John Mitchell, Herschel's rival in building large telescopes; see RAS W.2/3.4.

577 See Hoskin (2014a: 92). This book also contains reports of other guests (all visited the Herschels at Slough): the English novelist Frances 'Fanny' Burney (1752–1792) in August & December 1786 and 1787, the German novelist Marie Sophie Guntermann (1730–1807) in September 1786, Marc Auguste Pictet (1752–1825), Professor of Philosophy at Geneva University, in July 1787, Neville Maskelyne in October 1793 and Giambattista Rodella (1749–1834), mechanic at Padua Observatory, in November 1794. Because their reports do not contain important information about observing or technical matters, they are not treated here. For further visitors, see the 'Timeline' and 'Visitors' sections in the appendix.

578 RAS W.2/8.3.

579 Caroline's two other registers, the 'Register of Sweeps' (showing only the 'General number' of objects) and the 'Register of Gages' (showing only the number of stars counted), had an equal design. The page size is about 18.5" × 14.5".

580 The compact group is known as Arp 318. In the *Atlas of Peculiar Galaxies* of 1966, the American astronomer Halton Arp (1927–2013) had collected 338 cases.

581 Actually, it is a close double galaxy; the companion (IC 1559, 14.0 mag) is only 24" south. The Birr Castle assistant astronomer R. J. Mitchel (born in Galway, no dates) discovered the pair in 1857. He is credited for

83 NGC- and three IC objects.

582 On 7 December (sweep 485), Herschel had already discovered an open cluster, 1.4° east of the pair: NGC 1802 (VIII 41).

583 Herschel W. (1811: Fig. 13).

584 On 7 May 1787 (sweep 732), two more galaxies were found in the area: NGC 5035 (uncatalogued) and NGC 5047 (III 670), seen edge-on with axis ratio 5.

585 The hint is due to Caroline's 'Catalogue of the stars', RAS C.3/2.3.

586 Sometimes, a sweep was not numbered or the same number appears twice.

587 'Count de Brühl' is the German astronomer and diplomat Hans Moritz v. Brühl (1736–1809). Franz Xaver v. Zach (1754–1832) was a German astronomer and Director of Seeberg Observatory, Gotha, from 1786 to 1806.

588 The 'keyhole' in NGC 1999 should not be confused with the Keyhole Nebula in the Eta Carinae Nebula NGC 3372.

589 RAS W.5/12.1: 48–58; Maurer (2013). Andreas Maurer (1932–2013) was a Swiss engineer and amateur astronomer.

590 Dreyer (1912a: xlvi); see also: Hoskin (2003c).

591 RAS W.4/33.6.

592 Caroline's 'General catalogue' has 2508 entries, sorted by discovery date. Designation and position for 1785 were given for each object class (see Table 5-1). This document should not be confused with John's *General Catalogue* of 1864.

593 RAS W.4/25.

594 Herschel W. (1786a).

595 *Item2* appeared later and is not relevant here. Caroline prepared a large table with 1177 numbers, but entered positions only for the numbers 1–34 and 154–157 (taken from *Item4*).

596 This is the galaxy NGC 4179 (I 9) in Virgo, discovered on 24 January 1784 (sweep 118). It was found again on 20 December 1784 (sweep 349), not noticing the identity.

597 The object (III 1), only a small patch in the Orion Nebula, bears no NGC-number (see section 2.1.2).

598 Actually, Messier used the equinox of the discovery date in his catalogues.

599 There was even a third observation on 21 December 1786 (sweep 796), but this date was too late.

600 Herschel Mrs. J. (1876: 56).

601 The previous paper was read on 6 July, the following (and last of volume 76) on 22 June. Curiously, the latter is also due to Herschel; see Herschel W. (1786b).

602 From 3 July to 16 August 1786, William and Alexander were in Hanover, visiting Göttingen too (see section 2.5.3).

603 Hoskin (2018: 83).

604 Herschel Mrs. J. (1876: 62).

605 Herschel Mrs. J. (1876: 73).

606 Caroline's calculations can be seen in the document 'Nebulae' (RAS C.3/3.1). It contains objects from sweep 512 to 1112.

607 RAS W.1/1: 154–157. Jean Dominique Cassini (1748–1845), French Astronomer; Johann Schroeter (1745–1816), German amateur astronomer, who built a remarkable observatory at Lilienthal, near Bremen. About 1784, he bought some smaller mirrors from Herschel for building telescopes. In 1794, he constructed a 27-foot Newtonian with 20 inches aperture on an extraordinary alt-azimuthal mounting; see Cunningham, Orchiston (2015); Hope (2019).

608 Bode (1787, 1788).

609 All are galaxies, except V 10–12 = M 20 (Trifid Nebula) and II 316/17 = NGC 2371/72 (PN in Gemini).

610 For a general discussion, including all Herschel objects, see 5.2.

611 Herschel found one supernova remnant, the Veil Nebula in Cygnus, viewing the main parts: NGC 6992 (V 14), NGC 6960 (V 15) and NGC 6979 (II 206).

612 Herschel W. (1811: Fig. 8).

613 King and Collinder (Cr) are open cluster lists. The former refers to the American astronomer Ivan King (*1927), the latter to his Swedish colleague Per Collinder (1890–1975).

614 The quadrant (Q) measured the difference between zenith and elevation (E), i.e. Q = 90° - E (see section 2.1.6).

615 Rigel was seen as a double star (II 33) on 1 October 1781 in the second review (see Figure 1-12); it is only an optical pair.

616 NGC 1625 was discovered by John on 24 November 1827 and NGC 1622 by Johnstone Stoney in 1850 at Birr Castle.

617 Sometimes the dry spell lasted even longer; for instance, 77 minutes in sweep 580 (2 September 1786).

618 On 23 November 1827, John saw an "immense nebulous atmosphere" (h 363). Dreyer, using the 10-inch refractor at Armagh Observatory, noted: "much elongated nebulosity". Both observations were illusions, probably due to stray light.

619 Herschel never saw NGC 6543 again. It was the first planetary nebula to be observed with the aid of a visual spectroscope by the English astronomer and physicist William Huggins (1824–1910) on 29 August 1864. The Cat Eye Nebula is only 16' away from the northern Pole of the Ecliptic.

620 This was one of three similar cases: on 11 September 1787 the telescope was rotated from north to south between sweeps 753 and 754 and on 30 November 1788 from south to north between sweeps 873 and 874.

621 This is another case of finding an object twice in a sweep, after NGC 4754 in Virgo on 15 March 1784 (see Figure 2-49).
622 There is no physical connection: M 46 is 5400 light-years away, the planetary only 3000 light-years.
623 A similar case is NGC 750/51 in Triangulum, discovered in sweep 286 on 12 September 1784, but not resolved.
624 In the literature, the 11.6 mag galaxy MCG -2-33-61 is erroneously taken for NGC 4804 (IV 40); it is 55' north. The claim implies an 1° error in PD, which is ruled out by the sweep data. Though the bright galaxy is located in the areas of sweeps 210, 818 and 819, it was never observed by Herschel.
625 RAS W.7/8: 37.
626 According to Lubbock (1933: 144), this was Mr. Campion. The "very ingenious Smith", engaged by Herschel at Slough as workman at the 20-ft telescope.
627 The identity was eventually recognized by John: M 61 = I 139 = h 1202. In the problematic sweep 105 (23 January 1784), William already had taken M 61 for M 49 (see section 2.2.1).
628 'Lord Cavendish' is the British physicist Henry Cavendish (1748–1820). There is a nice anecdote. Sitting next to Herschel at dinner, he asked: "Is it true, Dr Herschel, that you see the stars round?" William briskly replied: "Round as a button"; Clerke (1895: 100). For the optical quality of Herschel's reflectors, see Ceragioli (2017).
629 However, on (sweep 568), Herschel wrote: "The time was disturbed by the weight of two Gentlemen who occasionally mounted into my seat."
630 A third companion, NGC 5569 (13.2 mag), located only 4' northeast of NGC 5566, was found in 1849 by Johnstone Stoney at Birr Castle.
631 A detailed description of the sweep method is given in section 5.1.
632 See section 2.2.6 for this strange case. The 'coarse cluster' 27' northeast of M 20 is one of the star groups in the area.
633 John Arnold (1736–1799), British watchmaker; Richard Howard, 4th Earl of Effingham (1748–1816).
634 Dietrich Herschel (1755–1827), William's younger brother. His eldest brother Jacob Herschel (1734–1792) died in Hanover by strangulation; see Latusseck & Hoskin (2003).
635 Herschel Mrs. J. (1876: 62).
636 RAS C.2/1.2.
637 RAS C.2/1.3.
638 RAS C.2/1.1: last page. On the last page of Caroline's *Sweeps No. 3*, we read "Multiplier for 1783 in Variation. 1' = 1',2917 in PD in space. 1" = 0",0861 in AR in time." The values are equal to 93/72 and 93/(72·15), respectively.
639 She used $^{h\,\prime\,\prime\prime}$ instead of $^{h\,m\,s}$.
640 Herschel Mrs. J. (1876: 61). Prince Charles is Charles II, Duke of

Mecklenburg-Strelitz (1741–1816), brother of Queen Charlotte. The Duke of Saxe-Gotha is Ernest II (1745–1804), founder of the Seeberg Observatory (Gotha). The 'Duke of Montague' is George Montagu, 1. Duke of Montagu (1712–1790).

641 Herschel Mrs. J. (1876: 151).

642 Alexander's 'Monkey Clock' was later used by John in his Slough sweeps, first on 9 May 1825 (sweep 4).

643 In 1833, Caroline wrote that the comet "was visible during 4 or 5 Months"; RAS C.4/3: 3.

644 In a letter to Dietrich at Hanover, dated 4 August, she described the place, writing: "I believe you have a pair of Harris's maps." Herschel Mrs. J. (1876: 71). It is not known, if this was a gift from William, made at his visit.

645 RAS W.2/3.5: 672.

646 Herschel W. (1811: Fig. 26).

647 Herschel Mrs. J. (1876: 58, 73). The wooden tube, 40 feet long and 5 feet wide, was built in a large barn in nearby Upton.

648 In the second review, 61 Cyg was identified as a double star (IV 18) on 20 September 1780.

649 Herschel's four galaxy quartets are listed in Table 2-29 and shown in Figure 2-104.

650 The front-view is also called 'Herschelian'; about the technical aspects of this optical design, see Hoskin (2011b) and Ceragioli (2017).

651 Even the ladder of the small 20-ft was not large enough, reaching about 15 feet in height.

652 In a letter sent to Schroeter in 1784, Herschel wrote: "I have another [slide device] on the opposite side in case I should want the left eye any longer time, but then of course the inclination of the speculum will require an alteration."

653 RAS W.5/15. The rare print was published by Herschel. The original copperplate and several copies are stored in the Herschel Archive of the *Royal Astronomical Society*.

654 See also 'Sweeping concerns', RAS W.7/2.1: following p. 52.

655 Herschel W. (1786a: 499).

656 Herschel W. (1787: 125).

657 M 31 and M 32 were seen better in the next night (sweep 618).

658 A third member, NGC 946 (III 198), was already seen on 6 October 1784 in the eastern sweep 283.

659 Herschel W. (1811: Fig. 41).

660 The name was coined by Max Wolf, who photographed the large emission nebula in July 1901; Steinicke (2010b).

661 'Dr. Hebberdon' is William Heberden (1710–1801), an English physician.

662 The visually found objects in Dreyer's *Index Catalogue* (IC) have a mean

brightness of 13.9 mag; the value for the NGC is 12.6 mag. This explains why Herschel discovered only nine IC objects (seven in the sweeps, only one was catalogued).

663 The workman probably was Mr. Campion, the “very ingenious Smith”. He was also engaged in the construction of the 40-ft (compare footnote 626).

664 NGC 1156 was catalogued in 1963 as a ‘reflection nebula’ (DG 11).

665 It was catalogued by the Canadian astronomer Sidney van den Bergh (*1929) as vdB 68.

666 The open cluster was catalogued by Collinder in 1931.

667 Caroline now used Bode’s star catalogue of 1801. The star was observed by Tobias Mayer and is contained in his catalogue of zodiacal stars of 1775. It is the variable FT Vir.

668 RAS W.3/1.10: 36. When observing Uranus in a sweep, Herschel always had looked for possible moons. For instance, on 28 February 1785 (sweep 374) he wrote: “No star near enough to be supposed a satellite.”

669 The moons were later named by John Herschel (see footnote 672).

670 Herschel W. (1787).

671 William Lassell (1799–1880) was an English amateur astronomer, who constructed equatorial Newtonians with apertures of 24 and 48 inches; the latter was used on Malta. He discovered four NGC objects.

672 William had not named his moons. Instead of choosing persons from Greek mythology, John named the four moons after magical spirits in English literature.

673 This claim was made by Paul Rincon in a BBC report, titled ‘Uranus rings were seen in 1700s’ and broadcasted in 2008; see also: Eves (2020). The (true) rings were detected in 1977 with an airborne telescope when Uranus occulted a star.

674 Herschel W. (1798).

675 If Herschel had indeed been successful, the rings would certainly not have escaped subsequent visual observers, using even superior telescopes.

676 This is the third case of finding an object twice in a sweep after NGC 4754 on 15 March 1784 (see Figure 2-49) and NGC 5839 on 24 February 1786; both are galaxies in Virgo.

677 It is possible that Herschel constructed his standard eye-piece to give this comfortable value.

678 For instance, in sweep 696, the reference star σ Aur was taken in the ‘parallel’ at ST $8^h\ 55^m\ 14^s$ with $\Delta T = -36^s$, i.e. the star was seen west of the meridian (preceding part). Due to a PD of 67°, it already was near the western edge of the field.

679 Steinicke (2011b).

680 See also: RAS W.3/1.10.

681 Although the westward view of the 20-ft was obstructed by the house, Uranus was clearly seen above the roof (see Figure 2-141).

682 Herschel W. (1789: 255).
683 The story of Enceladus and Mimas was told by Dreyer (1912a: li-lii).
684 All features of the instrument are described in the comprehensive report 'Description of a Forty-feet Reflecting Telescope', Herschel W. (1795b).
685 RAS W.5/12.1: 74, no. 291.
686 Dreyer (1912a: 498).
687 Herschel J. (1833a: Fig. 27).
688 Uranus and Mars were only 4° and 8° west of M 44, a remarkable conjunction.
689 RAS W.2/1.12: 13.
690 RAS W.5/12.1: 95.
691 Dreyer (1912a: 487).
692 This is one of 16 galaxies, discovered by Herschel, which are not catalogued in the NGC/IC (see Table 5-5).
693 Only three minutes after M 83 and 1.9° southeast, Herschel observed the 10.4 mag galaxy NGC 5253 (II 638) in Centaurus; it was his only find in this southern constellation (see Figure 5-20).
694 M 74 was the only Messier galaxy, observed with the 40-ft reflector.
695 Bode (1801), Lalande (1801), Baily (1847).
696 Ashbrook (1984: 352). Stephen Groombridge (1755–1832), British merchant and amateur astronomer. Groombridge 1830 is the star with the third largest proper motion, after Barnard's Star (Ophiuchus) and Kapteyn's Star (Pictor).
697 The eye-piece was called 'No. 5'; see Table 2-50.
698 NGC 6120 has a 15.3 mag companion: NGC 6119, 2.3' northwest, found by John in 1827 (h 1945). NGC 6137 has a companion too, only 1.8' north. John only saw the main galaxy, the other was not perceived, though with 14.7 mag it is even brighter than NGC 6119; the galaxy is catalogued as NGC 6137A. For the objects, later added to the NGC (marked by a suffix A, B,…) see Steinicke (2010a: 468).
699 The remarkable pair of double stars in Lyra was found on 28 August 1779 with the 6.2-inch reflector in the second review. It was catalogued as II 5/6.
700 Steinicke (2009a).
701 NGC 4657 is not a separate galaxy, but a part of NGC 4656, pulled out by the gravitational interaction between NGC 4627 and NGC 4656.
702 RAS W. 2/1.11: 24. 'Lord Huntingdon' is Theophilus Hastings, 11th Earl of Huntingdon (1728–1804); 'Lord Rodden' is the Irish peer Robert Jocelyn, 2nd Earl of Roden (1756–1820). 'Sir Harry' probably is Henry Charles Englefield, already called 'Sir Harry Englefield' by Caroline, when he visited Bath ca. 1778.
703 NGC 6229 has the concentration class IV.
704 RAS C.2/4.2.

705 Herschel W. (1791).
706 William's eldest brother visited Slough from April to October 1787. On 19 September he was shown Uranus in the 20-ft.
707 It is the only time, Herschel changed between the 20- and 40-ft in the sweep campaign. Later he used both reflectors for observations in 18 nights (mainly for Solar System objects).
708 See 1.3.2 for Herschel's chances to find the 8th planet.
709 John Lochée (1751–1791) was the royal sculptor. The bust is shown in the *National Portrait Gallery*; Hoskin (2003a: 93).
710 'Professor Sniadeki' is Jan Śniadecki (1756–1830), Polish mathematician and Director of Kraków Observatory. Caroline wrote: "Professor Sniadecky often saw some objects through the twenty-foot telescope, among others the Georgian satellites. He had taken lodgings in Slough for the purpose of seeing and hearing my brother whenever he could find him at leisure; he was a very silent man." Herschel Mrs. J. (1876: 75).
711 It is 20° north of Herschel's Garnet Star μ Cep, found on 27 September 1782.
712 Herschel W. (1791), Steinicke (2019b).
713 Steinicke (2016a).
714 Beside Méchain and Jean Dominique Cassini, the other French guests were the mathematician Adrien-Marie Legendre (1752–1833) and the instrument maker Simon Carochez (1740–1813).
715 Of course, Herschel saw the brightest members (M 31, M 32, M 33 and NGC 205), found earlier by others; see Table 2-25.
716 Steinicke (2012b).
717 The 'nebula' was shown to James Dunlop (1793–1848), visiting Slough on 16 December 1827; the Scottish astronomer catalogued 629 nebulae, found at Paramatta, Australia; see Steinicke (2010a: chapter 4.4), Cozens (2008).
718 Despite of its brightness of 12.3 mag, the extreme flat galaxy (axis ratio 9.5) is very difficult to observe. The object was found on a plate, taken in 1894 by the English amateur astronomer Isaac Roberts (1829–1904); he discovered 34 IC objects. For NGC 2537 and IC 2233 see Steinicke (2017b).
719 Maximilian Hell (1720–1792), Hungarian Jesuit astronomer, known for his account on the Venus transit 1769, observed on Vardø, Norway.
720 'b Crateris' is '3 Crt' in the *British Catalogue*. The star is now in Hydra, with no Flamsteed number; it is HR 4214 (5.4 mag), located 5.4° northeast of NGC 3242.
721 RAS W.2/1.12: 18. The 'Bishop of Landaff' is Richard Watson (1737–1816), Anglican Bishop of Llandaff and academic.
722 The red star was already observed on 1 and 10 April (sweep 823 and 830), but a colour was not noted. The name was coined in 1872 by the

Italian Jesuit astronomer Angelo Secchi (1818–1878), Director of Collegium Romanum Observatory, Rome. The spectroscopic pioneer was fascinated by the strange spectrum of this Carbon star. In the literature, Lalande is credited for the discovery. He observed the red star on 3 April 1791; see Steinicke (2015c).

723 Mary Pitt (1750–1832), née Baldwin, was known as Lady Herschel. Caroline, only three months older than Mary, was not amused about William's decision. She later destroyed all her personal records of that period. For the marriage and its consequences for the siblings, see Lubbock (1933), Hoskin (2010, 2011a, 2013), Winterburn (2017).

724 Steinicke (2020a).

725 Herschel used the term 'star with an atmosphere' again for NGC 1514 in Taurus (found in 1791). Such objects were finally discussed in Herschel W. (1791). However, NGC 2403 is missing in the paper.

726 Caroline rediscovered NGC 2403 on 31 July 1793 with the large sweeper.

727 Of course, M 33 and NGC 253 are larger, but they were found earlier by Hodierna (1654) and Caroline (1783), respectively.

728 The nearest find is the Local Group member NGC 185 in Cassiopeia at 2.2 million light-years.

729 Steinicke (2015a).

730 There is another H II-region to the east, missed by Herschel. It was discovered 1784 at Birr Castle by Ralph Copeland (1837–1905), the later Astronomer Royal for Scotland. Dreyer catalogued it as NGC 2363.

731 Herschel Mrs. J. (1876: 146).

732 The comet was rediscovered in 1939 by the French astronomer Roger Rigolett (1909–1981), thus it is periodic.

733 RAS C.1/1.2: 51, RAS W.2/1.1: 21; Herschel's letter to Banks of 3 March 1789: RAS C.1/3.2: 9.

734 Ridpath (2014) raised the question: "There is, though, a smudgy pencil mark near 82 Pegasi labelled 'Com' for which I can find no explanation. Is this perhaps an unannounced [comet] discovery? It is one of the many secrets awaiting elucidation." This puzzle could be solved in Steinicke (2015d).

735 The dense globular cluster NGC 2419 has a concentration class II; see Steinicke (2013b).

736 Herschel W. (1811: Fig. 20).

737 The 14.8 mag galaxy NGC 3671 (III 922) in Ursa Major, seen on 9 April 1793 (sweep 1039), is at the same distance. The record holder with 978 million light-years is NGC 5699 in Boötes, found on 16 May 1784 in sweep 218 (Figure 2-57).

738 Salvador Jiménez Coronado (1747–1813), Spanish astronomer; he later became Director of the first Madrid Observatory, which used the 25-ft reflector, built by Herschel for Charles IV, King of Spain. There is second

visit on 23 June 1789.
739 This is the English politician Thomas Bulkeley (1752–1822), 7th Viscount of Bulkeley.
740 Steinicke (2014c).
741 Steinicke (2020b).
742 Herschel W. (1811: Fig. 15).
743 RS MS/246.
744 RAS W.4/26.
745 The method will be treated in 4.1.
746 Herschel W. (1789).
747 The catalogues are closed items. However, there is a table giving the number of observations for each object over the whole sweep period; this is Caroline's 'Catalogue of 2500 Nebulae and clusters' (RS MS/345).
748 RAS C.1/1.2: 56.
749 RAS W.2/1.12: 50.
750 Tiberius Cavallo (1749–1849), Italian physicist. James Lind settled in the Windsor area in 1782, occasionally discussing scientific themes with King George III. About Herschel's connections in the Windsor area, see Lewin (2020).
751 Unfortunately, Herschel missed the conjunction of Uranus with M 44 on 12 October 1788; the planet was only 40' south of the cluster centre (the position was again reached on 1 November 1956). In September to October, he was engaged with sweeping.
752 R. J. Mitchel identified the object as a double nebula in 1856 with the 72-inch at Birr Caste. In the literature NGC 2474/75 is sometimes misidentified with the bipolar planetary nebula Emberson-Jones 1, located 30' north of the pair.
753 RAS C.1/1.2: 60.
754 RAS W.2/1.12: 55.
755 Herschel W. (1800a: 71).
756 RAS C.1/1.2: last page.
757 RAS C.1/1.2: 58. The field of view was measured by Caroline on 14 June 1792 to be 1° 46' 22.4": "It was determined by letting γ Virginis pass thro' the field; and the center supposed." (RAS C.1/1.2: 75). The field diameter was also measured by William on 12 May 1793, getting 1° 48'. Caroline added: "I measured it too; (tho' I never had any practice with that instrument) and found the diameter of the field of view 1° 49'." (RAS C.1/1.4: 14).
758 Lubbock (1933: 252).
759 RAS C.1/1.4: 1.
760 'Abbe Rochow' is Alexis-Marie de Rochon (1741–1817), French astronomer and marine optician. 'Abbe Ungeschick' is the Luxembourgish astronomer Peter Ungeschick (1760–1790). He was a student of Lalande in Paris, later working at Mannheim Observatory. Ungeschick died on his

way to London on 21 November at the early age of 30.
761 Equuleus contains only one other object, visible to Herschel: the 12.5 mag galaxy NGC 7015. Alas, it was missed.
762 Steinicke (2010a: 61, 153).
763 In sweeps 100 and 101 (23 January 1784), eye-pieces ‘No. 2’ and ‘No. 8’ are mentioned, respectively, though without giving any data.
764 RAS W.2/7: 32.
765 It was not Herschel’s first one. On 24 February 1766 he watched a total “Eclipse of the Moon at 7 o’clock AM” at Kirby Hill; RAS W.7/8: 20.
766 Herschel W. (1792: 27).
767 Herschel W. (1791).
768 The Polish Prince Michał Jerzy Poniatowski (1736–1794) became a Fellow of the *Royal Society* in 1791. This event might be the occasion for visiting the Herschels at Slough.
769 RAS W.2/8.3: sheet AR XII–XIV, PD 30°–47°.
770 Herschel J. (1864).
771 John contributed some more cases (all were entered in the NGC by Dreyer): 50 Cas (4.0 mag) = h 179 = NGC 771, β CVn (4.3 mag) = h 1332 = NGC 4530, 19 Pup (4.7 mag) = h 3115 = NGC 2542 and 3 Mon (5.0 mag) = h 373 = NGC 2142.
772 Dreyer (1912a: 444).
773 Dreyer (1912b: 536, footnote).
774 It was independently discovered by the French astronomer Stephane Javelle (1864–1917) in 1891 with the 30-inch refractor oft Nice Observatory. He discovered 1355 IC objects.
775 RAS W.2/8.1.
776 RAS C.1/1.4.
777 Note that Caroline’s *Journal No. 4* gives a wrong date (27 July). William’s ‘Messier marathon’ was on 2 August 1783 with 18 M-objects.
778 RAS W.2/1.12: 56.
779 RAS C.1/1.4: 3.
780 This confirms that there were notes, made at the telescope. Like in the sweeps they were, obviously, destroyed later (see section 2.1.4).
781 RAS C.1/1.2: 73.
782 RAS C.1/1.4: 27.
783 RAS W.2/1.12: 72.
784 RAS C.3/1.1: 52. ‘Mr. Brinkley’ is John Brinkley (1763–1835), first Astronomer Royal for Ireland, working at Dunsink Observatory. ‘Mr. Greatheed’ is the English dramatist Bertie Greatheed (1759–1826). ‘Professor Blumenbach’ is Johann Friedrich Blumenbach (1752–1840), German physician and naturalist, working at Göttingen University.
785 Karl Felix v. Seyffer (1762–1822), German astronomer.
786 With regard to the Herschel family, William found himself in a certain bottleneck position until he married Mary Pitt. His parents had 10

children (see Introduction), but only Sophia Elisabeth, Alexander and Dietrich were married. The problem: there was no male descendant with the name Herschel. Sophia Elisabeth had eight children, including George Griesbach (1757–1824), Dietrich had only one, Anna Elisabeth (born 1783); Alexander was childless. With John's birth in 1792, 53-year-old William eased the situation. John Herschel restored the original condition: on 3 March 1829, he married Margaret Brodie Stuart and the couple got no fewer than 12 children, including three sons!

787 Herschel's tours are compiled in RAS W.7/15 (see also the Appendix). Jean-Baptiste Komarzewski (1744–1810) was a Polish lieutenant-general and mineralogist. In the luggage was the 7-ft 'skeleton reflector'; tube and stand consisted of metal bars which could be screwed together and taken apart so as to occupy very little space. However, there is no documented observation, made on the trip.

788 James Watt (1736–1819). On 18 June 1807, the Scottish engineer and his wife Ann (1738-1832) were guests at Slough; Herschel Mrs. J. (1876: 113).

789 Lubbock (1933: 233–237).

790 Herschel wrote a report on John Mitchell's telescope: RAS W.7/14: 19. On 5 August 1793, he was again at Thornhill to by the instrument for 30 pounds. His owner had died on 21 April.

791 However, Sirius was seen in the 40-ft: "The transit of large stars, unless where none of the 6th or 7th magnitude could be had, have generally been declined in my sweeps, even with the 20 feet telescope. And I remember, that after a considerable sweep with the 40-ft instrument, the appearance of Sirius announced itself, at a great distance, like the dawn of the morning, and came on by degrees, increasing in brightness, till this brilliant star at last entered the field of view of the telescope, with all the splendour of the rising Sun, and forced me to take the eye from that beautiful sight. Such striking effects are a sufficient proof of the great sensibility of the eye, acquired by keeping it from the light." Dreyer (1912b: 34).

792 Joseph Haydn (1732–1809), Austrian composer. The event is entered in Caroline's visitor book, stored at the Herschel Museum, Bath. In Haydn's daybook, describing his journey to England, incorrectly the 14th is given.

793 Observations with the 40-ft telescope, RAS W.2/4: 5.

794 Joah Bates (1741–1799), English musician; see Winterburn (2014: 213).

795 Steinicke (2006a). The double star was catalogued as N86.

796 Edward Gregory (1744–1824), Rector of Langar, Nottinghamshire.

797 RAS C.1/1.2: 76.

798 Actually, there are five galaxies in the field; the others are NGC 2288, NGC 2291 and NGC 2294, all discovered by Johnstone Stoney with the 72-inch at Birr Castle in 1849. However, NGC 2291 is as bright as

Herschel's objects and only 3' northeast of NGC 2289. Perhaps it was not recognized due to its compact appearance.
799 Hoskin (2014a: 101).
800 Herschel W. (1794).
801 RAS C.1/1.2: 79.
802 RAS W.2/1.12: 90.
803 There is no sweep 1061.

3. Final sweeps and the later years

After a break of three years, the sweeps were continued in late

November 1797. However, the campaign no longer was William's central task. He was interested in stellar magnitudes and building large reflectors of 24 inches aperture. He also defined the 'power of penetrating into space' for telescopes in general. Caroline discovered her 7th and 8th comets and wrote a book on Flamsteed stars, published by the *Royal Society* in 1798. In 1802 the last sweeps were made by the siblings and the third and final catalogue of nebulae and clusters was published. After the sweep campaign, William continued his observations of Messier objects. The last years were dedicated to the Solar System, inspired by a new type of objects: asteroids. After his death in 1822, Caroline hastily moved back to her hometown Hanover – and became increasingly unhappy with her decision. At the same time, John followed in his father's footsteps as an astronomer.

3.1. Stellar magnitudes, the 7th comet and Caroline's first publication

Although there were no sweeps between 18 October 1794 and 22 November 1797, William's astronomical activity was substantial. He used 86 nights in 1795 and actually 103 in 1796. Caroline observed in 16 nights in 1795; 10 of them along with her brother, though each was watching separately. She made no observations in 1796.

After a break of 59 days, Caroline started observing on 11 January. She believed to have seen a "very small comet, but it is so very near the horizon that there is no finding of its brightness". On the 12th the case was cleared: "What I saw last night was the 2nd of the Connoiss. des temps [M 2 in Aquarius]." On 13 January, William took over, observing double stars in Cetus and Aries with the 7-ft.

Another reason for not sweeping were single stars. Permanently using the *British Catalogue*, William became increasingly frustrated about Flamsteed's data. Already Caroline had found errors, mainly concerning position and identification of stars. But his complaint was different: it concerns brightness. He found that the magnitude values in the *British Catalogue*, commonly used as a standard, were not reliable.

Thus, William's goal was a new brightness scale. In March, he

started appropriate observations. This eventually led to the 'First catalogue of comparative brightness'. The manuscript, written by Caroline, was finished on 1 January 1796. It was read to the *Royal Society* on 25 February 1796 and appeared in volume 86 of the *Philosophical Transactions*. The lengthy title is 'On the method of observing the Changes that happen to the fixed Stars; with Remarks on the Stability of the Light of our Sun, and a Catalogue of comparative Brightness of Stars, for ascertaining the Permanency of the Lustre of the Stars'. A second catalogue followed six months later; two more were published in 1797 and 1799.[804] This shows the importance of the issue, which involved a lot of time.

In the first catalogue, Herschel wrote that "Flamsteed did not compare the stars to each other, but referred each of them separately to his its imaginary standard of magnitude." He gives striking examples, like this one in Leo: "σ by Flamsteed is 4.5m, ι φ υ λ κ π ξ are all marked 4m, and therefore ought to be larger; but σ is larger than any of them." Thus, correct magnitudes were urgently needed. He finally inspected 38 constellations with a total of 1905 stars.[805]

All observations were laid down by Caroline in the *Review* series. We see cryptic entries, like: "Cassiopeia 1--2 3,1 7.3.8-5". William had created a complex notation to express brightness differences between Flamsteed stars (here 1, 2, 3, 5, 7 and 8 Cas). The entry means: 1 Cas is a considerable difference brighter than 2; 3 is the least perceptible difference brighter than 1; 7 equals 3; 3 equals 8; 8 is a very small difference brighter than 5.

Herschel spent all his time on this task. Even when away from Slough, he compared the brightness of stars in a constellation, mostly with the naked eye. There were several occasions in 1795. On 3 April he was in Bath and 29 August in Gloucester. In September he visited Glastonbury, Bridport, Blandford, Salisbury, Andover and Newbury.

Planets, non-stellar objects and the 20-ft were rather neglected that year. However, on 16 August (at Sough), Herschel believed he had found a comet: "An object that may be a Comet […] The object is like a pretty bright nebula irregularly round a small brightish nucleus with faint chevelure, it makes a rectangle with, 7 feet Refl.

Double eye glass. It is just visible in my finder. By the finder it is about 3¼° north of Cor Caroli.” It soon turned out that the object was the bright galaxy M 94 in Canes Venatici. Alas, William never discovered a comet.806

This was different for Caroline. On 7 November at 9:30 pm, he found her 7th exemplar, using the large sweeper (Figure 3-1). The 5.6 mag comet was seen 2.5° northwest of γ Cyg, 40° above the western horizon. William checked the situation. It was followed until the 28th, by then a 4.5 mag object in Ophiuchus. In 1819 Johann Encke revealed that Caroline’s comet was identical to the one, discovered on 17 January 1786 by Méchain, and later appearances.807 The object was named Encke’s Comet, after the person who found the periodicity. Caroline was the first to see its reappearance.

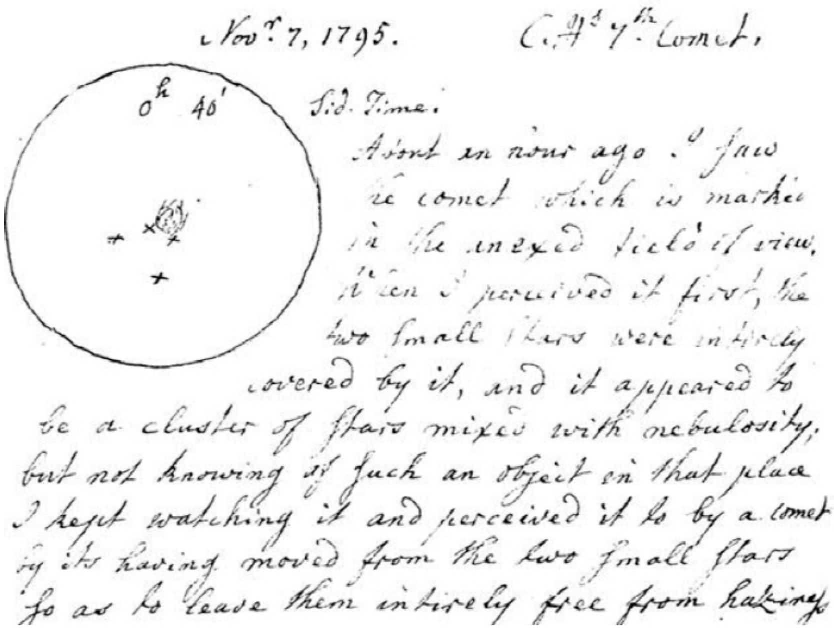

Nov. 7, 1795. C. H.s 7th Comet.
0h 40' Sid. Time.
About an hour ago I saw the comet which is marked in the annexed field of view, when I perceived it first, the two small stars were intirely covered by it, and it appeared to be a cluster of stars mixed with nebulosity, but not knowing of such an object in that place I kept watching it and perceived it to be a comet by its having moved from the two small stars so as to leave them intirely free from

Figure 3-1: On 7 November 1795, Caroline found a 7th comet, later known as Encke’s comet.

Herschel’s stellar observations were interrupted only shortly and went on in 1795 until 30 December. He observed on 86 nights. In his campaign, lasting until the end of 1799, 15 double stars were

found with the 7-ft. He was well-trained for such objects through the star reviews, made with the same instrument in 1779–83.

Herschel observed alone in 1796, viewing stars and planets. A curious event happened on 4 March, when Uranus was seen in the 20-ft. He noted at 10:35 pm: "About 13' preceding and 5 or 6' north of the Georgian Planet is a nebula, small, irregularly round, much brighter middle, like a bright nucleus, about 2 or 3' np a small star, being out of the meridian, the estimations may be a little faulty." The nebula was found in Leo, 23° west of the meridian at 10° altitude (of course, the 'round motion' was used). Due to the tilted view, the orientation in the field was a bit difficult. Actually, the nebula was 13' west (Figure 3-2). Herschel catalogued it as I 272; his position is only 4' northwest of a 12.3 mag galaxy. Dreyer lists the object as NGC 3332.

Already on 18 January 1784 (sweep 83), Herschel had found a nebula, entered in the first catalogue as III 5. He wrote a lengthy note, accompanied by a finder and telescopic sketch:[808]

North following ρ Leonis. The faintest & smallest nebula imaginable. I viewed it a long while and a higher power than the sweeper. Both delineations are from memory only, but the Telescope is pretty well to be depended on; The finder not at all. Having no person at the clock, I went in to write down the time, and having been in the light and looked at the white paper in writing I found it impossible to recover the nebula. There are some small stars and the nebula can not be far from them. It appeared like a very small nebulous star, and is probably of the cometic sort, there was another very small star south following (I think, or rather am pretty sure) and it preceded a pretty bright star, such as I think must be visible in my finder. It was nebulous with the higher power as well as the sweeping piece; and I must look for it another night after having been a sufficient time in the dark. It should have been shewed before I went into the light. Its place must be about 2½ degrees following ρ Leonis & about 10' more north than that star.

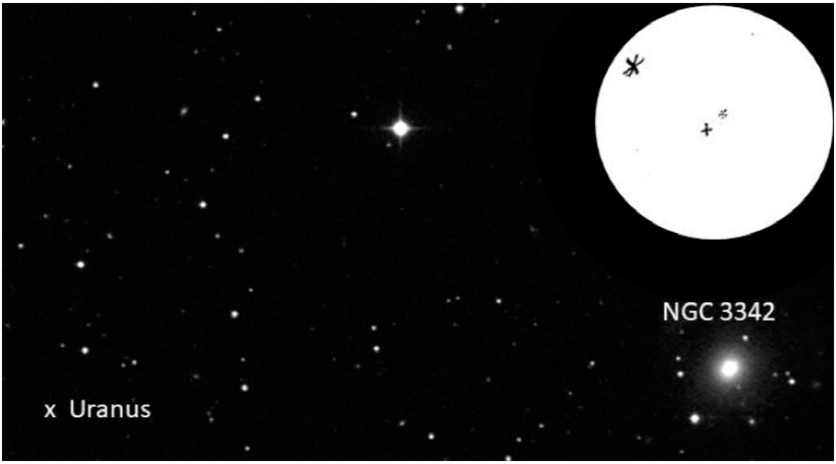
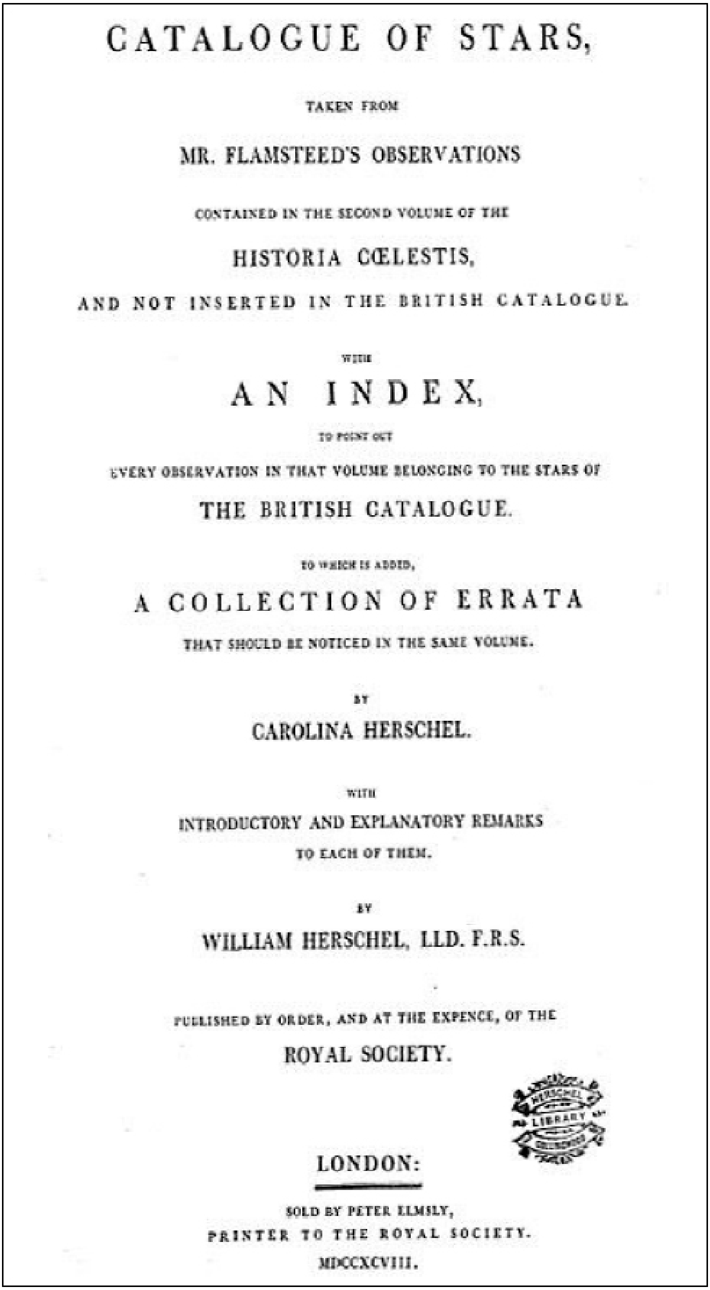


Figure 3-2: When viewing Uranus on 4 March 1796, Herschel saw NGC 3342, 13' west, known since 18 January 1784 (Inset).

Caroline determined a position, which was 37' northeast of I 272. Dreyer catalogued III 5 as NGC 3342. However, due to William's description and the sketches, this is I 272, having a 9.9 mag star 8' northeast. Thus, we finally get: III 5 = I 272 = NGC 3332 = NGC 3342. Of course, John could not find 'both' nebulae.[809]

On 1 June, the manuscript of the second catalogue of the comparative brightness of stars was finished. It was sent to the *Royal Society* and read already on the 9th. The work on the third part was already in progress. As usual, it was Caroline's task to compile the data and write the manuscript.



CATALOGUE OF STARS,

TAKEN FROM

MR. FLAMSTEED'S OBSERVATIONS

CONTAINED IN THE SECOND VOLUME OF THE

HISTORIA CŒLESTIS,

AND NOT INSERTED IN THE BRITISH CATALOGUE.

WITH

AN INDEX,

TO POINT OUT

EVERY OBSERVATION IN THAT VOLUME BELONGING TO THE STARS OF

THE BRITISH CATALOGUE.

TO WHICH IS ADDED,

A COLLECTION OF ERRATA

THAT SHOULD BE NOTICED IN THE SAME VOLUME.

BY

CAROLINA HERSCHEL.

WITH

INTRODUCTORY AND EXPLANATORY REMARKS

TO EACH OF THEM.

BY

WILLIAM HERSCHEL, LLD. F.R.S.

PUBLISHED BY ORDER, AND AT THE EXPENCE, OF THE

ROYAL SOCIETY.

LONDON:

SOLD BY PETER ELMSLY,

PRINTER TO THE ROYAL SOCIETY.

MDCCXCVIII.

Figure 3-3: Title page of Caroline's famous book on Flamsteed stars (*Catalogue of Stars*), published by the *Royal Society* in 1798.

But Caroline also did astronomical desk work herself. In autumn 1795, William made the suggestion that she could list all errors, found in Flamsteed's *British Catalogue*. In April 1797 he wrote:[810] "I recommended it to my sister to undertake the arduous task. At may request, and according to the plan which I laid down, she began the work about twenty months ago, and has lately finished it." He was convinced that the result should be published. The production was made in several steps:[811] at the end of February 1796, she wrote all observations on slips; this work was finished on 1 June 1797. On 24 December 1797, Caroline received the notice from the *Royal Society* to prepare the work for printing. The copy was sent to London on 8 March 1798 and in summer she proofed the print. The book was finally published in late 1798 (Figure 3-3).[812]

The book has three parts: (1) 'Catalogue of Flamsteed stars, not included in the British Catalogue', (2) 'Index to Flamsteed's observations of the fixed stars contained in the second volume of the Historia Coelestis', (3) 'Errata in the observations of the fixed stars contained in Flamsteed's second volume of the Historia Coelestis'.[813] The making explains why there were no observations by Caroline or sweeps between December 1795 and August 1797. However, her assistance was not used either – William also had no time. His last sweep (1063) was dated 18 October 1794 and the next (1064) would not be made until 12 November 1797.

3.2. Restart of sweeping

3.2.1. The 25-ft reflector and Caroline's 8th comet

In January 1796, Herschel was commissioned to build a 25-ft reflector for the King of Spain, equipped with a 24-inch mirror.[814] The large speculum was cast in August. Already on 24 January 1797 the reflector, known as the 'Spanish telescope', saw first light. Due to the good experiences with the 20-ft, the instrument was designed as a front-view; the tube was supported by a 'classical' triangular stand. He wrote:[815] "25 feet Telescope, 24 inches Aperture. Speculum No. 1. The stars pretty well defined. No rays but some considerable aberration."

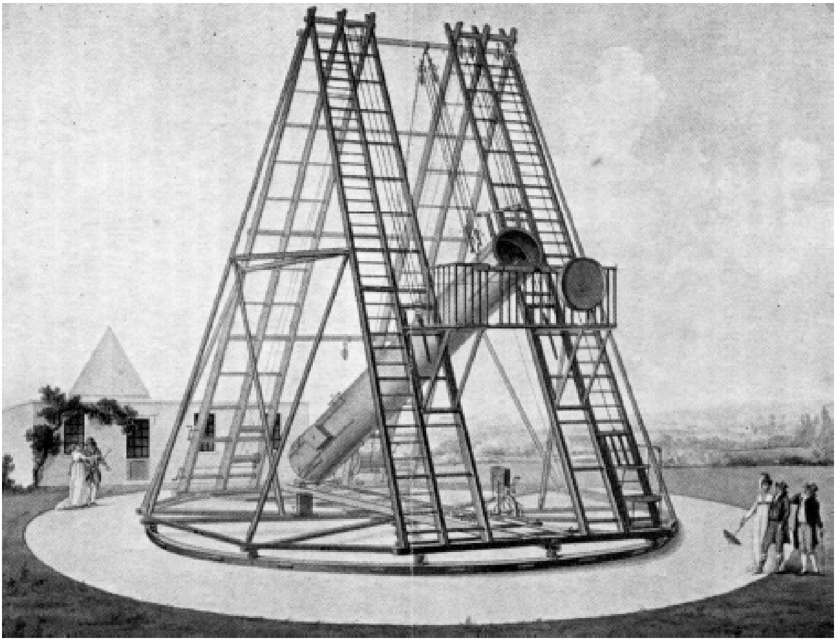


Figure 3-4: The 25-ft ‘Spanish telescope’, equipped with a 24-inch mirror; note the front-view design.[816] Though first erected at Slough in 1798, the drawing shows a fictional place.

The large reflector was fully operational in March 1798 (Figure 3-4). It was erected next to the 20-ft Together with the 7-, 10-, 20- and 40-ft (equipped with mirrors of 6.2, 9.0, 18.7 and 48 inches diameter), Herschel directed a spectacular telescope ensemble in his garden (another 24-inch reflector would follow soon). In 1805 the 25-ft was delivered to Spain. The telescope data are given in Table 3-6.

Figure 3-5: A perfect replica of Herschel's 25-ft 'Spanish telescope' is on display in Madrid.[817]

In the first quarter of 1797, Herschel observed Uranus and stars for his brightness review. The manuscript for the third catalogue of comparative brightness of stars was finished on 12 April; it was read to the *Royal Society* on 18 May. The work appeared the same year in volume 87 of the *Philosophical Transactions*.[818]

William observed until 25 July, when he left Slough for about a month. Caroline found time for observing on 14 August (after a break of 625 days) – and immediately made an important find: her 8th comet! The 3.7 mag comet was located in Lynx. She wrote:

At 9^h 30' common time being dark enough for sweeping I began in the usual manner with looking over the heavens with the naked eye, and immediately saw a comet nearly as bright as that which was discovered by Mr. Gregory [of Nottinghamshire] Jan. 8, 1793. I went down from the observatory to call my Brother Alexander that he might assist me at the clock. On my way in the Garden I was met & detained by Lord Storker and another Gentleman who came to see my brother and his telescopes. By way preventing too long an interruption I told the Gentlemen that I had just found a comet and

wanted to settle its place. I pointed it out to them and after having seen it they took their leave.[819]

Caroline made a naked-eye sketch and some sketching at the small sweeper (Figure 3-6). On the 16th, she wrote: “Tuesday morning the 15th, I went to Greenwich and carried out my memorandums to Dr. Maskelyne. When I arrived there, he had no intelligence yet of the comet. In the evening Dr. M. received a letter from Stephen Lee Esq. who had also seen it on the 14th. I had the pleasure to find that my observations agreed perfectly with Mr. Lee’s.”[820] Caroline followed the comet until 28 August. At that date, William was back at Slough and “saw my Sisters 8th comet near α Ophiuchi with her small Sweeping Instrument. It had the same appearance as all the former small comets I have seen. The evening was not fine enough to apply large instruments.”

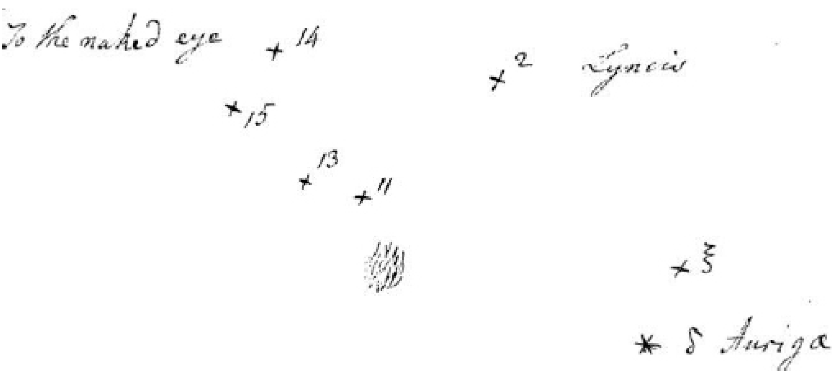


Figure 3-6: On 14 August 1797, Caroline found her 8th comet (in Lynx); with 3.7 mag it was visible to the naked eye.

Caroline’s eight comets are listed in Table 3-1, but not all of those objects ended up being credited to her.[821] Either way, she was the best female comet explorer for a long time. Her fantastic record has only recently been surpassed by another ‘Caroline’ – the American astronomer Carolyn Shoemaker, who discovered 32 comets.[822] William never found a comet. Table 3-2 shows all ‘supposed’ comets, seen by the siblings.

Comet	Date	Tel	Con	V	Remarks
1	1 Aug. 1786	SS	Leo	3.2	
2	21 Dec. 1788	SS	Lyr	7.0	Rigolett 1939, periodic
3	7 Jan. 1790	SS	Vul	5.6	
4	17 Apr. 1790	SS	And	7.1	
5	15 Dec. 1791	LS	Lac	7.1	
6	7 Oct. 1793	LS	Oph	5.6	Messier, 27 September 1793
7	7 Nov. 1795	LS	Cyg	5.6	Méchain 1786, Comet Encke, periodic
8	14 Aug. 1797	E	Lyn	3.7	Lee, Bouvard 14 Aug.

Table 3-1: Caroline's eight comets. SS/LS = small/large sweeper, E = naked eye; no. 6 is credited to Messier; no. 7 was rediscovered; no. 8 was also by also others.

Date	Obs	Tel	Con	Type	Object	Remarks
13 Mar. 1781	W	7-ft	Gem	planet	Uranus	
5 Aug. 1782	W	7-ft	Ser	GC	M 5	
30 Oct. 1783	W	20-ft	Scl	Gx	NGC 7507 (II 2)	sw 7
13 Dec. 1783	W	20-ft	Cet	Gx	NGC 596 (II 4)	sw 44
18 Dec. 1783	W	20-ft	Cet	?		sw 47, near δ Cet
19 Dec. 1783	W	20-ft	Cnc	Gx	NGC 2775 (I 2)	sw 57
23 Jan. 1784	W	20-ft	Vir	Gx	M 49 (I 7)	sw 105, JH's comment (GC 3146)
12 May 1784	C	SS	Cyg	OC	NGC 6819	
19 Jul. 1786	C	SS	UMa	Gx	M 82	M 81 was correctly identified
14 Jan. 1789	C	SS	Peg	?		near 82 Peg
18 Aug. 1789	C	SS	?	?		
7 Nov. 1792	C	SS	Sct	OC	M 11	
8 Jul. 1793	C	LS	CVn	Gx	NGC 4449 (I 213)	
24 Oct. 1794	C	LS	Oph	GC	M 14	
11 Jan. 1795	C	LS	Aqr	GC	M 2	
18 Aug. 1795	W	7-ft	CVn	Gx	M 94	

Table 3-2: The supposed comets, seen by William (W) and Caroline (C). Except three, all could be identified.

In October 1797, Caroline left her cottage and "went to lodge & Board with my brother's workman (Sprat) who's wife was to attend on me."823 Now, being separated from William and his wife Mary, though being still in Slough, she nevertheless could use her instruments, installed on her roof 'observatory': "My telescopes on the roof to which I was to have occasionally access; as also to the room with the sweeping and observing apparatus which remained in its former order, where I most days spent some hours in preparing work for me to go on with at my lodgings."

The period without sweeping ended on 22 November – after 1131

days! Caroline was on her usual place. All sweeps of 1797 (1064–75) were made in the north, under the pole, inspecting parts of Draco, Camelopardalis, Cepheus and Ursa Minor. This met the demand to cover the sky near the pole. Moreover, objects GN 2426 to 2450 were discovered and the question of an end arose. William's 60th birthdays was near (15 November 1798) and he knew that there was no chance to reach the number 3000.[824] Of course, 2500 would be a realistic goal.

On 10 December (sweep 1066), a remarkable galaxy pair was found in Draco: NGC 4291 and NGC 4319 (I 275/76). The 11.5 and 12.0 mag objects were 6.2' distant (Figure 3-7). A new double star (N118) was formally used as the reference star for both objects. Its place was settled two days later in sweep 1068 by the star '5 Draconis Hevelii', listed in Wollaston's catalogue.[825] This was a typical method in the star-poor northern regions. Now NGC 4291 is described as "Very small, considerably bright, the preceding corner of a trapezium; verified with 320 on account of its smallness." The galaxy became prominent in recent times.[826] A little later, Herschel saw the small edge-on galaxy NGC 4572 (III 939); the 11.7 mag object has an axis ratio of 5. Later a meteor crossed the field of view (perhaps this was a belated Leonid).

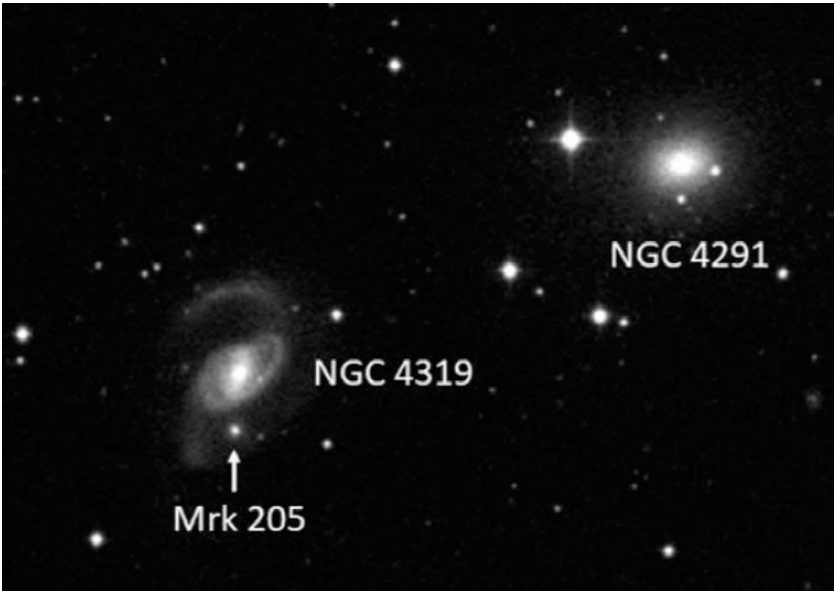


Figure 3-7: The galaxy pair NGC 4291 and 4319 in Draco was found on 10 December 1797. NGC 4319 is known for the claimed physical connection with the quasar Mrk 205, located only 42" south.

On 12 December (sweep 1068) another edge-on galaxy was seen in Draco: NGC 4331 (III 942). The 14.0 mag object with axis ratio 6 was viewed with 320×. In sweep 1070, a very close double nebula was found in Ursa Minor. The 13.8 mag galaxies NGC 5909/12 (III 943/44) were only 47" apart.

On 20 December (sweep 1074), Herschel discovered NGC 5295 (III 946) and NGC 5640 (III 949) in Camelopardalis; the faint galaxies (14.3 mag, 14.7 mag) are among his objects with the highest declination (see Table 3-8). Then Herschel saw a new nebula in Ursa Minor, writing: "Very faint, small, resolved. It is preceded by a small patch of stars which appears like this nebula, but more resolved." The primary object is the 14.5 mag galaxy NGC 5712 (III 950). The 'patch' is another galaxy, IC 4470, 4' northwest. The 14.4 mag object is seen edge-on (axis ratio 5). The uncatalogued galaxy is the last of eight Herschel objects, listed in Dreyer's *Index Catalogue* (Table 3-3); most of them are galaxies.[827] Except IC 3668 (I 179), a part of NGC 4668, none appears in Herschel's catalogues. Note that the galaxy IC 1339 in Capricornus was found with the 40-ft telescope (Figure 2-174).

IC	Con	Type	V	Date	Sw	Tel	Remarks	Dreyer
4665	Oph	OC	4.2	15 Jul. 1781	-	7-ft	de Chéseaux 1745	Bailey (1896)
780	Com	Gx	12.9	6 Apr. 1785	393	20-ft		Javelle (1893)
4996	Cyg	OC	7.3	20 Sep. 1786	594	20-ft		Bellamy (1903)
257	Per	Gx	12.6	11 Dec. 1786	645	20-ft		Swift (1888)
944	Boo	Gx	13.4	19 Mar. 1787	720	20-ft	pair with IC 946	Swift (1888)
946	Boo	Gx	13.4	19 Mar. 1787	720	20-ft	pair with IC 944	Swift (1888)
3668	CVn	GxP	13.0	9 Apr. 1787	725	20-ft	I 179; in NGC 4668 (I 178)	Wolf (1903)
1339	Cap	Gx	13.2	29 Sep. 1791	-	40-ft	ecliptic sweep	Javelle (1891)
4470	UMi	Gx	14.4	20 Dec. 1797	1074	20-ft		Bigourdan (1887)

Table 3-3: Herschel's IC objects, sorted by date. All, but IC 4665, were discovered by him. Dreyer was not aware about this fact, crediting other observers in the *Index Catalogue*.[828]

In sweep 1075 (same night), the 14.4 mag galaxy NGC 6331 (III 951) was found in Ursa Minor. It was seen only once. What is remarkable about this object, except its faintness ("extremely faint, small, 320 shewed it better"). It is the reference star, mentioned in

the third catalogue, finished in autumn 1802: “4 Cephei of Bode’s Cat.” How could this star be used in December 1797, whereas Bode’s catalogue was published not until 1801? Looking at Caroline’s ‘original’ sweep record, we learn that because no reference star was observed, the “nebula observed in [sweep] 1071” was used. This is the 11.2 mag galaxy NGC 6217 (I 280) in Ursa Minor, found on 12 December. It was referenced by 35 Dra and observed again in sweep 1075, half an hour before NGC 6331 (1.6° west). A better star, ζ UMi, was used in a further observation on 6 December 1801. Meanwhile, Bode’s catalogue was available and ‘4 Cephei’ was used for NGC 6331 in the final catalogue.

In March 1798, Herschel observed with the new 25-ft ‘Spanish telescope’. He noted on the 3rd: “Upon the Georgian planet with 200 and 300 it acts very capitally.”[829] A remarkable observation followed on the 12 March at 10:20 pm. Herschel had pointed the large tube at Hydra:[830] “25 ft reflector power 200. It brings the small stars to a very fine point. There is a double nebula in the field of view, the preceding certainly large, irregularly round, brighter middle, resolved. The 2nd small, pretty faint, large brighter middle. As the telescope is not in the meridian, I cannot determine their places but by the finder it is in a line λ υ^2 υ^1 Hydra continued; & as far from υ^1 as υ^1 is from λ.” There is no doubt that he has seen the galaxy pair NGC 2992/93, nearly in the meridian at 25° altitude (see Figure 2-90). This was Herschel only non-stellar object, viewed with this telescope. The pair had already been discovered as III 277/78 on 8 February 1785 in sweep 371.

Finally, on 14 March the 25-ft was again, directed at Uranus: “The Georgian planet is better defined in this instrument, than I have ever seen before. With 300 the disk is very well defined, as sharp as that of Jupiter.” Obviously, the ‘Spanish telescope’ was an incredible instrument.

The first seven sweeps in 1798 were made in the north, above the pole (1077–1083). However, they only started on 9 September. The period before was dedicated to Saturn. Caroline was only active in three nights (29 and 30 August, 1 September). She monitored, for instance, the variable star Algol with the naked eye.

Figure 3-8: A spectacular cosmic pair in the Cepheus Milky Way: the open cluster NGC 6939 (7.8 mag) and the face-on galaxy NGC 6946 (8.8 mag); the distance is only 40'. Herschel discovered both objects on 9 September 1798.

In sweep 1077 (9 September), Herschel discovered an exceptional cosmic duo in Cepheus. It consists of the open cluster NGC 6939 (VI 42) and the galaxy NGC 6946 (IV 76); see Figure 3-8. The unequal partners were only 40' distant. This is one of only two cases where he found a pair of non-stellar objects, in which both partners were not galaxies.[831] NGC 6939 (7.8 mag) is described as “A beautiful compressed cluster of stars, extremely rich, of an irregularly form, the preceding part of it round, and branching out on the following side; both towards the north and towards the south.” For the 8.8 mag galaxy NGC 6946, seen three minutes later, we read: “Very large, considerably faint. A spot of a bright nucleus, irregularly

formed, the nebulosity extends to 6 or 7'. The nucleus seems to consist of some very faint stars. It is a pretty object; the nebulosity is of the milky kind." Both objects are in a crowded region of the Milky Way, 12° away from the galactic equator. Therefore, the galaxy shines through the 'zone of avoidance'. Without the dimming caused by interstellar matter, NGC 6946 would be an impressive object.

Another pair was seen on 9 December (sweep 1085) in Taurus, 9° south of Aldebaran: "Two, exceedingly faint, within 1' of each other, in the meridian, very small." This is NGC 1633/34 (III 952/53) with 13.5 and 14.1 mag, only 40" apart; the latter has a high surface brightness (see Figure 2-101 and Table 2-28). On the next night (sweep 1087), an extreme edge-on galaxy with an axis ratio of 7 was found: NGC 1247 (II 900) in Eridanus, 12.5 mag bright.

3.2.2. A revolutionary reflector, the 'X-foot'

The turn of the year 1798/99 was filled with work on the manuscript of William's fourth catalogue on the comparative brightness of stars. It was finished by Caroline on 28 January and read to the *Royal Society* on 21 February. The paper appeared the same year in volume 89 of the *Philosophical Transactions*.[832]

Observing started on 30 January 1799 with sweep 1089. An open cluster was found in Puppis: NGC 2421 (VII 67). This shows that Herschel was also willing to fill gaps in the south. Indeed, the northern sweeps were interrupted by missions in Sagittarius, Sculptor, Eridanus, Canis Major and Puppis.

On 3 & 4 March, Herschel observed in Bath. He viewed some double stars with the 7-ft. Back in Slough, Uranus (in Leo) was his target. On the first night (3 April) he wrote:[833] "In the beginning the finder not being adjusted I made a few oscillations with the telescope in order to find the planet, and perceived a nebula. Its description is as follows; considerably bright, pretty large, irregularly round, very gradually brighter middle, about 3 or 4' in diameter. From the extent of my oscillations I suppose that it cannot be more than 3 or 4 degrees from the place of the planet."

Only one object comes into question: the 12.2 mag galaxy NGC 3611, 3.5° west and 35' north of the Uranus. Herschel could not identify the nebula, but it was II 521, found on 27 January 1786 in sweep 514; under hazy conditions it now appeared "faint, very small, easily resolvable, irregularly formed". On the 8th, he wrote: "I oscillated many degrees for the Nebula or Comet seen April 3 but could not find it."

The night of 8 April also brought another view of the planetary nebula NGC 3242 (IV 27) in Hydra. Under the impression of his 'star with an atmosphere', which pushed the idea of true nebulous matter, he wrote: "There is a possibility of its consisting of stars; but in that case they must be united so as to make a very capital center for attracting other celestial bodies. Their union in this manner cannot be accounted for by attraction only; which would bring on destruction without projectile motion."

The next sweep (1090) was made on 29 June. Herschel found an interesting pair in Hercules: NGC 6500/01 (III 957/58). The 12th mag galaxies show a separation of 2.2'. Then there was another longer break until the next sweep (1091) on 19 December.

On 19 August, Caroline visited the Royal Observatory, Greenwich. Invited by Nevil and Sophia Maskelyne, she stayed for 11 days.[834] Shortly after, the Astronomer Royal, impressed by her friendly character and scientific knowledge, sent a gift, some binoculars and a 'night-glass'. The Maskelynes had become close friends of Caroline.

In July and August, William observed several Messier objects with the 10- and 20-ft reflectors. Then, from 20 to 29 August, he stayed again in Bath at Alexander's home. There a compact telescope was in the making: a Newtonian with 24 inches aperture and only 10 feet focal length. With an aperture ratio of 1:5 it was a true light bucket, not built for high magnification but for viewing faint, large objects.[835] Herschel called it the 'large 10-ft' or simply 'X-foot' – a "convenient instrument for an old man".[836] Due to the short tube, it was very easy to handle. Often the eye-piece could be reached from the ground; for higher altitudes the stand was equipped with a short front ladder.[837] The innovative reflector was used at Bath for first views of deep-sky objects:[838]

24 August. I viewed several objects with my new large 10 feet Newtonian 24 inches aperture but the mirror is not polished properly & wants distinctness. The apparatus is excellent I can get any objects in less than half a minute.

28 August. The 10ft telescope is considerably improved; but is not nearly finished. I viewed the nebula in Andromeda [M 31], the cluster in Aquila [M 11]; that in the Swordhandle of Perseus [NGC 869/84]; the 15th of the Connoissance [M 15] etc. but being so well acquainted with these objects I saw nothing new in them.

29 August. The telescope is again rendered more distinct. With 140 it now resolves the 3rd [M 3] and shews that no. 75 [M 75] is composed of stars; and is a miniature of the 3rd near 9 Bootis. No. 72 [M 72] np 8 Aquarii is a minute cluster of stars. It seems not to have a Nucleus, tho' much condensed. My planetary IV. 1 [NGC 7009] is a beautiful object; it is certainly quite different from the planetary Nebulae seem to be single bodies, of an amazing size of course.

Back in Slough, Herschel was visited by Professor Vince, who stayed from 2 to 4 September:[839]

I shewed Mr. Vince the 15th, 13th and 2nd of the Con. etc.; the planetary Nebula near ν Aquarii [NGC 7009]; the nebula in Andromeda, the cluster of stars in the Swordhandle of Perseus [and the double stars] γ Andromeda, γ Delphini, ζ Aquarii etc. All which objects he saw as I have described them." Probably the 7-ft was used. In the next night "I shewed Mr. Vince the planetary Nebula in the hand of Andromeda [NGC 7662]. The 57th of the Con [M 57]; and a Sweep in the milky way with the 20-ft. He saw the milky way resolved into stars: the black circle in the 57th. The black circle is excentric being nearer to the circumference on one side than another. Mr. Vince also saw this.

In the third night, Herschel showed the planetary nebula NGC 6818 in Sagittarius with the 20-ft. Then he demonstrated the power of the 40-ft to his guest: "I examined the Nebula No. 2 of the Con. [M 2] It appeared very brilliant and luminous. The scattered stars were brought to a good well determined focus from which it appears that the central condensed light was not owing to a confusion arising

from the aberration of the scattered light but was owing to the multitude of stars that appeared at various distances behind & near each other. Besides, I could actually see and distinguish the stars even in the central mass. Power 240." Obviously, Vince was not the only visitor, since Herschel added: "Mrs. Vince, Mrs. Herschel [Mary], Miss Whites, Miss Wilson, Miss Baldwin also saw it."[840]

On 8 September we see a sign of life from Caroline. After a break of 372 days, there is an entry in her observing book: "My brother shewed me the comet (of which he had notice from Mr. Lee who saw it Sept. 5) in the 20 ft. reflector. Of all the comet I have seen, it is the most solid appearance." The 4.3 mag object, discovered by Méchain, was in the drawbar of Ursa Major. William observed the comet on the 10th with 300× and followed it until 14 September.[841] Caroline saw it one last time on 4 October (in Ophiuchus) with the small sweeper. It would take another 818 days until her next observation, on 31 December 1801.

On 7 October, Caroline finished her "Catalogue of omitted stars made for Dr. Maskelyne".[842]

On 19 December, sweep 1091 was made in Eridanus. It brought an interesting pair: "Two, the 1st very bright, small bright nucleus with faint branches from np to sf. The 2nd is close to it; or about 1½' sf the former; it is very faint, very small." Herschel first saw the 10.3 mag galaxy NGC 1332 (I 60). Then, in the same field and 2.8' southeast, the 13.4 mag galaxy NGC 1331 (III 959) appeared; note the reversed order in the NGC (see Figure 2-134). Why is the pair interesting? The bright galaxy had already been discovered in sweep 331 on 9 December 1784 – without its fainter partner. Herschel noted at that time: "Small, very bright, little extended, much brighter middle." Why was the companion missed, though the night was fine? Obviously, this was due to the optical design. In 1784 the 20-ft was a Newtonian, but in 1799 we have the front-view. An analysis shows that the magnitude limit was about 0.3 mag lower with the new optical design – an essential advantage for faint objects (see Table 2-43). Finally, what is the reason for the reversed order in the NGC? Caroline is the cause. In her *Zone Catalogue*, prepared for John's sweeps, she gave an AR 3 17 57 for the first component (I 90), according to sweep 331. A second line

gives 3 17 14, based on sweep 1091. Because of the proximity of the components, she listed the same value (3 17 14) for the following nebula (III 959). John missed that subtle difference, taking 3 17 57 for I 60 and 3 17 14 for III 959. Unfortunately, he never observed the pair, so it bears no h-number. It is only listed in his *General Catalogue* of 1864. There we have I 90 = GC 709 and III 959 = GC 708 – the perfect reverse order. Dreyer, not doubting John's authority, consequently set NGC 1331 = GC 708 = III 959 and NGC 1332 = GC 709 = I 60. All such cases are shown in Table 3-4.843

NGC	GN	H	Sw	Date	V	Con	Remarks
704	1494	III 563	599	21 Sep. 1786	12.8	And	in Abell 262
703	1495	III 562	599	21 Sep. 1786	13.3	And	in Abell 262
1332	668	I 60	331	9 Dec. 1784	10.3	Eri	Figure 2-134
1331	2466	III 959	1091	19 Dec. 1799	13.4	Eri	Figure 2-134
4342	309	III 96	191	13 Apr. 1784	12.5	Vir	
4341	310	III 95	191	13 Apr. 1784	13.2	Vir	
4892	974	II 390	396	11 Apr. 1785	14.0	Com	in Coma Cluster
4889	975	II 391	396	11 Apr. 1785	11.5	Com	in Coma Cluster, Figure 2-88
4973	2085	III 781	921	14 Apr. 1789	13.9	UMa	
4967	2087	III 783	921	14 Apr. 1789	14.2	UMa	

Table 3-4: There five cases, in which Dreyer's NGC-numbers do not match the AR order (Herschel's sequence is correct). All objects are galaxies.

In sweep 1091 (28 December), Herschel discovered his last open cluster, NGC 1342 (VIII 88) in Perseus. On the same night the bright face-on galaxy M 74 in Pisces was viewed with the 40-ft (see section 2.6.3).

3.2.3. Summary of 1795–99

There were no sweeps in 1795 and 1796. The year 1797 starts with no. 1064 on 22 November and ends with no. 1075 on 20 December. 1798 starts with no. 1076 on 5 September and ends with no. 1088 on 10 December. 1799 starts with no. 1089 on 30 January and ends with no. 1092 on 28 December.

In 1795, William started his observations of stars to revise the brightness scale. He toured through southwest England for 20 days. Caroline found her 7th comet. In 1796 William published two

papers on stellar brightness (two more appeared in 1797 and 1799) and one on the 40-ft. Caroline found her 8th comet and left her cottage for other accomodation in Slough. The 'Spanish telescope' saw first light. In 1798 William had his 60th birthday and his sister's book on the Flamsteed stars was published by the *Royal Society*. In August 1799, Caroline visited the Maskelynes at Greenwich.

Category	1797	Remarks	1798	Remarks	1799	Remarks
number of nights	6		9		4	
longest continuous period (days)	2		2		1	
longest break (days)	(1131)	18 Oct. 1794 – 12 Nov.	259	20 Dec. 1797 – 5 Sep.	173	29 Jun. – 9 Dec.
number of sweeps	12		13		4	
mean night (hours)	4.0		2.7		0.9	
longest night (hours)	6.7	1071	7.0	1088	1.2	1091
lowest elevation (°)	60	20 Dec.	8	9 Dec.	19	19 Dec.
highest elevation (°)	67	PD 62°	81	PD 48°	76	PD 53°
lowest PD (°)	9	20 Dec.	25	16 Sep.	34	10 Jul.
observed objects	31		16		16	
objects per night (mean)	5.2		1.8		4.0	
sweeps without objects	5		5		-	
new objects (all)	26		9		10	
uncatalogued objects	1		-		-	
re-observed objects	5		7		6	
most productive night	12 Dec.	11 objects	10 Dec.	8 objects	19 Dec.	9 objects
first object		NGC 4589 (Gx Dra)		NGC 6907 (Gx Cap)		NGC 2421 (OC Pup)
last object		NGC 6331 (Gx UMi)		NGC 2327 (Gx CMa)		NGC 1342 (OC Per)
brightest object (mag)	10.7	NGC 4586 (Gx Vir)	7.8	NGC 6939 (OC Cep)	6.7	NGC 1342 (OC Per)
faintest object (mag)	14.7	NGC 5640 (Gx Cam)	14.1	NGC 1634 (Gx Tau)	13.4	NGC 1331 (Gx Eri)
smallest object (")	24	NGC 5295 (Gx Cam)	24	NGC 1634 (Gx Tau)	54	NGC 1331 (Gx Eri)
discovered multiple systems	1	pair	1	pair	1	pair
observed Messier objects	-		-		-	
new double stars	1		4		1	
new garnet stars	-		-		-	
star gages	2		4		1	
vacant places	-		-		-	

Table 3-5: Sweep statistics for the years 1797 to 1799.

3.3. A new century

3.3.1. The power of penetrating into space

In the first half of 1800, Herschel prepared an important publication, titled 'On the Power of penetrating into Space by Telescopes; with a comparative Determination of the Extent of that Power in natural Vision, and in Telescopes of various Sizes and Construction; illustrated by select Observations.' The manuscript was finished on 20 June, but was only read to the *Royal Society* on 21 November.[844] Instead of using magnification, he considered another quantity to measure the 'space-penetrating power' of a

telescope: “It will not be difficult to shew that the power of penetrating into space by telescopes is very different from magnifying power, and that, in the construction of instruments, these two powers ought to be considered separately.” Herschel writes about optical concepts like exit and entrance pupil, although he did not use these modern terms. The result of his treatment is a simple formula for the ‘space-penetrating power’.

Let’s start with the exit pupil.[845] A bundle of parallel rays emerges from the focused eye-piece (actually, a reduced image of the telescope opening). It appears as a bright round spot (best seen in daylight), which does not fill the eye-piece (Figure 3-9). Its diameter is the exit pupil (p), calculated by $p = A/m$, where A is the aperture and m the magnification. For the 20-ft ($A = 18.7$ inches, $m = 157$) we get $p = 0.12$ inches (Herschel omitted the leading 0 for decimal numbers < 1, writing .12).

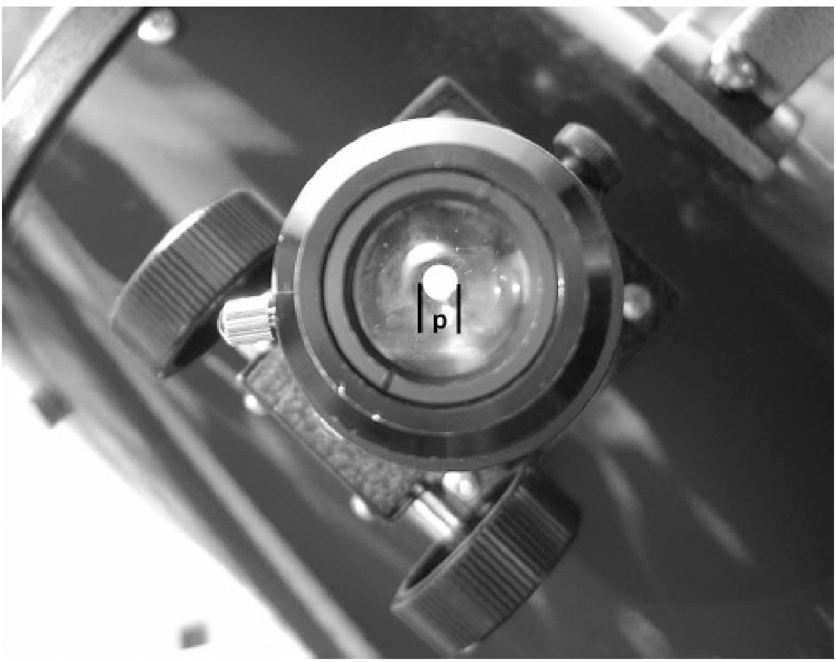


Figure 3-9: The exit pupil is the bright round spot of diameter p, not filling the eye-piece.

The iris is a diaphragm, which reacts on bright light. It

automatically reduces the entrance pupil to protect the sensitive parts on the retina, especially the optical nerve. In daytime, its diameter (a) is about 0.5 inches (2 mm). When going into darkness, a slowly increases (dark adaptation). Herschel wrote: “On taking notice, in the beginning of sweeps, of the time that passed, I found that the eye, coming from the light, required near 20' [minutes], before it could be sufficiently reposed to admit a view of very delicate objects in the telescope … we shall suppose a [to be] 2 tenths of an inch [5 mm], as being perhaps nearly the general opening of the iris, in star-light nights, when the eye has been some moderate time in the dark.”846 He had a nice method of keeping the adaptation: “I have taken sweeps of the heavens, of four, five, or six hours duration, that the sensibility of the eye, in consequence of the exclusion of light from surrounding objects, by means of a black hood which I wear upon these occasions, has been very great.” In order to secure complete “tranquility of the retina”, he used to remain 20 minutes in the dark before attempting to observe faint objects; and his eye became so sensitive after hours of sweeping, that the approach of a third-magnitude star obliged him to withdraw it from the telescope.847

Entrance and exit pupil are basic factors for visual observing: “the aperture of the eye is also concerned in viewing with telescopes; and that, consequently, whenever the pencil of light transmitted to the eye by optical instruments [p] exceeds the aperture of the pupil [a], much light must be lost.” Thus, for no loss, we should have $p < a$. For constant aperture (A) and entrance pupil (a), the relation depends only on magnification (m). For $A = 18.7$ inches and $a = 0.2$ inches, there is no light loss for all magnifications used by Herschel (157× to 360×). The critical value is 94×; at lower power, some light is lost (vignetting). Of course, to view a large, faint nebula, $p = a$ is the ideal choice. Now maximum light reaches the optical nerve. For greater exit pupils, even lower powers can be used.

Herschel’s ‘penetrating power’ (P) is now defined as the ability of an optical instrument to produce bright images of faint celestial objects. The basic advantage of the telescope against the naked eye is its larger aperture, i.e. a greater light-sampling ability. Herschel concluded “that the artificial power [telescope] of penetrating into

space should be to the natural one [eye] as A to a." Thus, we have P = A/a.

But this is an oversimplification. Other factors must be taken into account, which modify the numerator (A). In the case of a Newtonian reflector, not only the aperture of the main mirror (A) must be considered, but also that of the secondary (b). Thus, Herschel changed A into $\sqrt{A^2 - b^2}$. Another factor is reflectivity. He knew that his metal mirrors have a reflectivity of 67.2%. Therefore, a double reflection (primary and secondary) yields 45.2%. This factor, called x (in decimal values, i.e. 0.672 or 0.452), was put under the square root. Thus, the resulting formula for the 'space-penetrating power' is:

$$P = \frac{\sqrt{x \cdot (A^2 - b^2)}}{a}$$

Herschel entered a, A and b in tenth of an inch; x has no dimension. For a front-view we have b = 0; the same applies for a refractor (x is now the transmission of the lens system). He gave some examples and tries to explain his successful/unsuccessful observations by means of P. The entrance pupil was always taken as a = 0.2 inches. Table 3-6 shows the collection of telescopes (including John's 18¼-inch reflector[848]). The 'space-penetrating power' ranges from 12.8 (small sweeper) to 191.7 (40-ft).[849]

Name	A (in)	F (ft)	R	Focus	S (in)	P	Years	Sites	Obs
10-ft	9.0	10	13.3	N	1.6	28.7	1776–1818	B, D, C, S	W
small 20-ft	12.0	20	20.0	N	1.5	39.0	1776–1783	B, D, C, S	W
7-ft	6.2	7.1	13.7	N	1.2	20.3	1778–1818	B, D, C, S	W
small sweeper	4.5	2.3	6.0	N	1.2	12.8	1783–1817	D, C, S	C
20-ft (N)	18.7	20	12.8	N	2.1	61.2	1783–1786	D, C, S	W
20-ft (FV)	18.7	20	12.8	FV	-	75.1	1786–1813	S	W
40-ft	48.0	40	10.0	FV	-	191.7	1787–1814	S	W
large sweeper	9.6	5.25	6.6	N	2.1	28.6	1790–1817	S	C
Spanish telescope	24.0	25	12.5	FV	-	95.9	1797–1801	S	W
large 10-ft, X-foot	24.0	10	5.0	N	3.0	78.1	1799–1811	S	W
new 20-ft	18.25	20	13.1	FV	-	75.0	1820–1832	S	J

Table 3-6: 'Space-penetrating power' (P) for reflectors, used by the Herschels. A = diameter of primary mirror (aperture), F = focal length, R = F/A (aperture ratio); Focus: N = Newtonian, FV = front-view, S = diameter of secondary mirror; Sites: B = Bath, D =

Datchet, C = Clay Hall, S = Slough; Obs (observer): W = William, C = Caroline, J = John.

The publication about the ‘space penetration power’ was followed by three papers on the Sun. The first contains Herschel’s famous discovery of the thermal radiation (infrared).[850] This subject is not treated here.

The year 1800 brought only one sweep (1093), made on 21 January. Only a non-stellar object and a double star were seen, both were already known. The former is the open cluster NGC 1817 (VII 4) in Taurus, discovered on 19 February 1784 in sweep 147. The double star is N124 = III 93, found on 31 December 1782. No Messier object was viewed in 1800. William observed on 42 days. His main target was the Sun, observed with the 7- and 10-ft reflectors. From 4 to 18 February, and again on 3 December, he visited Alexander in Bath. Caroline stayed there from 4 July until November to take care of a house, owned by Lady Herschel.[851]

3.3.2. The mysterious northern sweep 1096

On New Year’s Day 1801, the minor planet Ceres was discovered by Guiseppe Piazzi, Director of Palermo Observatory. This important event would affect Herschel for many years. However, he was only informed about the find by the Italian astronomer on 2 September.[852] Of course, he was not amused about the delayed message.

Although only 12 sweeps were made in 1801, the year brought the record of 176 observing days. William mainly monitored the Sun. Caroline had only one observation – on 31 December!

On 4 January, Herschel saw M 77: “Nebulosity near δ Ceti. If I had the right object, the description of its place given Sep. 20, 1783 is not right, instead of 2 degrees it should be about 1° if so much. Having a new finder I cannot estimate accurately but it seems to be less than ¾ degree. The direction is right enough from η Pisc through δ Ceti. On examination I find the observation says 2/3 degree, which I mistake for 2°. In the 10-ft telescope, I see a few stars with seeming nebulosity of no great extent.” It is strange that he speaks about the “Nebulosity near δ Ceti”, whereas the

observation of 1783 clearly mentions M 77. The Messier object was again seen on the 14th: "Large X feet telescope. No. 77 of the conoiss; about 2 fields of the double eye piece, power 120, south following δ Ceti. Some small stars with nebulosity about them. Nothing remarkable." This is part of the story about NGC 1055, already told in section 2.1.4. The night also brought the first observation of M 42/43 with the new compact reflector.

On 15 March, the first sweep of the year was made in Puppis (1095), yielding no new objects. On 1 April, Saturn was viewed with both the 25- and 40-ft telescope. The former "shews Saturn very well. By limiting (stopping) the aperture to one half of its diameter [12 inches] it shews the planet in higher perfection of distinctness than my 10 feet." This was Herschel's last observation with the excellent 'Spanish telescope'. In contrast, the 40-ft was in a rather bad condition: "The speculum is much injured by times. I see the phenomena however, of the ring the belts the shadows the satellites etc. very well."

The next sweep (1096), on 2 April 1801, was made in the north, above the pole. It brought mysterious results – and much confusion to later astronomers, like John Herschel, Auwers, d'Arrest, Bigourdan and Dreyer. The issue concerns the 15 nebulae discovered in the sweep, covering parts of Draco and Camelopardalis (AR range 3^{h}, breadth 3° 58'). The objects were catalogued as I 282–84, II 903–05 and III 963–71. The nebulae I 284, III 967 and III 968 form a trio, seen in a single field; III 967/68 form a pair (distance 7'), following I 284 by 10'.

The problem: the positions, determined by Caroline, do not match the existing objects. The first to notice this was John. Equipped with his aunt's legendary *Zone Catalogue*, he swept the northern region on three nights (2 September 1828, 4 and 5 April 1832). He 'saw' six objects and entered them in the *Slough Catalogue*: III 963, II 903 and II 905 are catalogued as h 612, 653 and 917.[853] Although John noted "eF" or "very doubtful", there is nothing at his places. Three objects (h 676, 733 and 795), located in the area, were declared as new ('Nova') – they were actually William's. The other nine nebulae of sweep 1096 were not found by John and got no h-number. Nevertheless, he entered all 15 nebulae in the *General*

Catalogue (GC) of 1864; the nine objects, not found by him, are listed at their nominal places (precessed to 1860).

When Arthur Auwers revised the three Herschel catalogues in 1862, he also failed for the 15 nebulae.854 However, for this task no new observations were made. Moreover, the German astronomer had no access to Caroline's sweep records or the *Zone Catalogue*. Two years later, Heinrich d'Arrest observed a large number of Herschel nebulae with the fine 11-inch Merz refractor at Copenhagen Observatory (Figure 6-11).855 The objects of sweep 1096 were not found. However, the Danish astronomer saw two nebulae in the region, thought to be new. When compiling the *New General Catalogue*, Dreyer was also irritated by this case. He could only do bookkeeping, assigning NGC-numbers to the 15 nebulae (based on the GC). However, John's novae and the two d'Arrest objects were also catalogued with separate numbers. At the end of the 19th century, the French astronomer Guillaume Bigourdan started an ambitious mission to observe all NGC objects with the 12.5-inch refractor at Paris Observatory.856 Again, Herschel's 15 northern nebulae were not found. Altogether, the various reports and catalogues present a strange mix of existent, not found and identical objects.

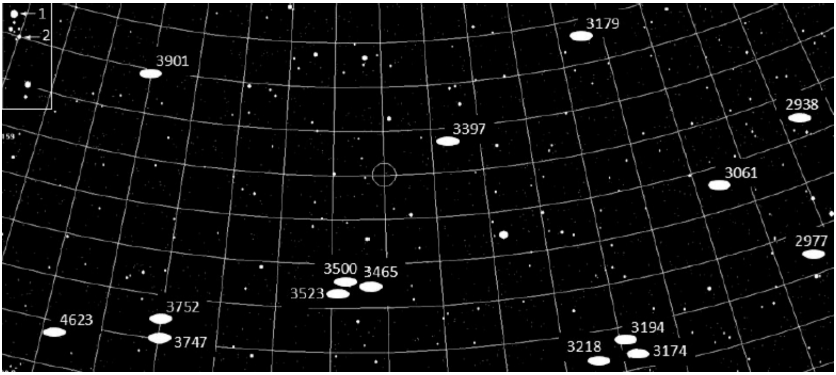


Figure 3-10: The 15 nebulae of sweep 1096, made on 2 April 1801, according to their true positions (see text). Note the upper left rectangle, containing relevant stars (see Figure 3-12); the central circle shows Herschel's field of view (15').

About 1910, Dreyer, having access to Herschel's original documents

at the *Royal Astronomical Society*, made a new attempt to solve the puzzle. For the upcoming *Scientific Papers* (see section 3.2.3), which were to contain revised versions of the three catalogues, he wanted a convincing solution before the manuscript went to the *Royal Society*. Consequently, Dreyer asked the Greenwich astronomer William Christie to take plates of the northern region.[857] The images of 1911 brought a clear result: all 15 nebulae existed![858] The ensemble is shown in Figure 3-10. However, the differences between the true and Herschel's positions were large. Dreyer was convinced that William or Caroline had made a systematic error. Unfortunately, he could not present any reason for it in the *Scientific Papers*. This unsatisfactory situation continued until the present author was able to find the solution in 2013. Of course, it is based on the sweep records, especially Caroline's 'Original' (Figure 3-11).[859]

Four unknown stars were observed in sweep 1096 on 2 April; William estimated their brightness as 8 mag, 6–7 mag, 7 mag and 6 mag. As usual, Caroline checked the catalogues of Flamsteed and Wollaston. Because the result was negative, she took the last star as a provisional reference star. Only relative positions could be given, referring to the (uncorrected) readings of the sidereal clock and the PD string. The method was based in the justified hope that the positions of the stars would be fixed by a later sweep.

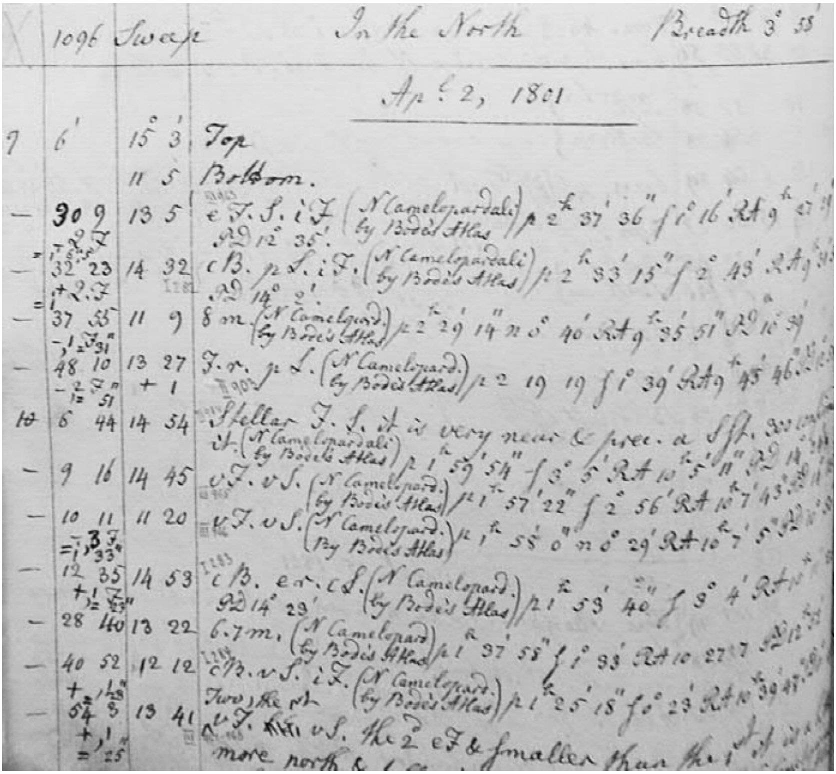


Figure 3-11: The first page of Caroline's record for sweep 1096 ('Original').

When in sweep 1099 (11 May) five stars were seen in Camelopardalis and Draco, the fifth was found in Wollaston's catalogue as '5 Draconis Hevelii'. The fourth, estimated as '6.7m' (6–7 mag), was seen 5^{m} 22^{s} preceding and 2° 23' north. Caroline was sure that the latter was her provisional 'reference star' of sweep 1096. Now, with the aid of '5 Draconis Hevelii', its absolute position was known – and also that of the 15 nebulae (and the other three stars of the sweep). When she later revised all sweeps and arrived at no. 1096, Bode's catalogue of 1801 was at hand. Now a suitable candidate for the 'reference star' was found: '208 N Camelopardali'. Moreover, Caroline revealed that this star was also in Wollaston's catalogue, called '4 Draconis Hevelii'.

Nevertheless, she had a bad feeling about the choice, since there was a difference between the position, based on sweep 1099 and

that, determined in 1096: “4 Draconis Hevelii as taken from Bode’s Cat. (NB Woll. & Bode agree) gives 1 46 mode minus than when it was determined (in the Original Sweep) by 5 Draconis Hevelii of 1099 Sw.” Anyway, as the last star of sweep 1096 was now ‘known’, Caroline designated the first three as ‘unknown stars’ U^{1096}, U^{1097} and U^{1098} in the revised sweep record. Note that U^{1098} and the Hevelius star were the last two objects, seen in the sweep. Curiously, Dreyer introduced two more stars in his analysis and calculated offsets to them; thus, his nebulae positions in the *Scientific Papers* deviate from Caroline’s. But it is clear that there is no error in her calculations, based on the sidereal clock and PD readings (which both were reliable) and the star positions of Wollaston and Bode (showing no difference).

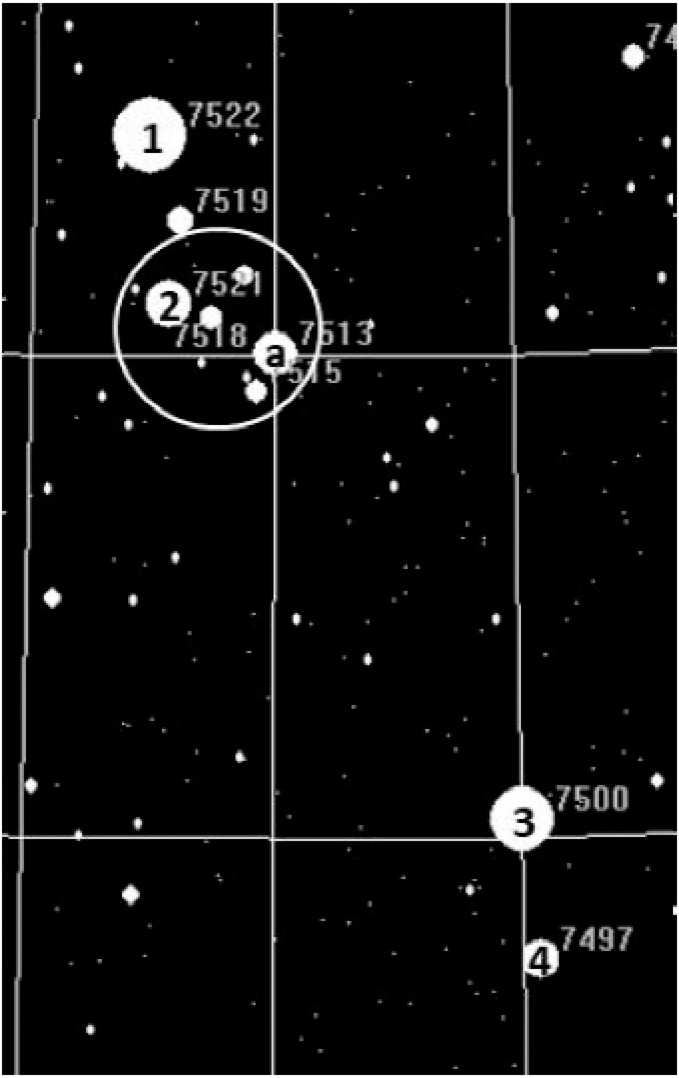


Figure 3-12: The stars at the top end of the problematic northern sweep 1096 (compare the rectangle in the upper left corner of Figure 3-10 where the stars 1 and 2 are marked). The grey numbers refer to the SAO star catalogue (see text).[860]

We are now ready for the puzzle solution. The key is in the last two stars. By the relative position, U^{1098} is close south of the Wollaston star. Indeed, there is such a pair in the suspected area (Figure 3-12): 1 = SAO 7522 (5.1 mag) and 2 = SAO 7521 (6.8 mag). By

Wollaston's coordinates, SAO 7522 is '4 Draconis Hevelii'. The offsets to U^{1098} seem to fit (Caroline: p 16^s, s 8', real sky: p 30^s, s 10') and also the magnitudes. Everything looks fine. But astonishingly, in this star-poor region of southern Camelopardalis, we encounter a second, very similar pair, located 45' southeast. The components are 3 = SAO 7500 (5.8 mag) and 4 = SAO 7497 (7.3 mag); the offset of the latter is p 20^s, s 9'. Will the real pair please stand up?

It actually is the second one (3, 4)! This astonishing conclusion is based on the following fact: 2 = SAO 7521 has a companion, a = SAO 7513 (6.8 mag), 7' southwest. If the first pair had really been seen, the pair '2 + a' should have appeared in the field of view (circle) and there would be another unknown star (a). Thus, we conclude that the true reference star is 3 = SAO 7500 and U^{1098} = 4 = SAO 7497. Wollaston's '4 Draconis Hevelii' (1) and its partner (2) are definitely out of the race.[861]

Now we have, for the first time, a reliable fixed point in the sky. Given the position of SAO 7500 one can calculate the positions of all the other objects, the 15 nebulae and the two remaining 'unknown' stars U^{1096} and U^{1097}.

The result perfectly match the existing galaxies (Table 3-7) and the two stars, now identified as SAO 6948 (6.2 mag) and SAO 7194 (7.7 mag). It then turned out that the objects found by John Herschel and d'Arrest, catalogued by Dreyer as new, were identical to some of William's. There was even one, he had already found, III 971 (NGC 3939) of sweep 1096, that was identical to III 640 of sweep 1068 (12 December 1797), catalogued by Dreyer as NGC 3890.

ST	H	NGC	h	GC	V	True α (^{h})	Δα (^{m})	Δδ (')	Remarks
09 30 09	III 963	2938	(612)	1883	13.5	9.27	8.6	16	NF
09 32 29	I 282	2977		1906	12.5	9.39	6.0	15	
09 48 10	II 903	3061	(653)	1970	12.8	9.60	7.5	17	NF
10 06 44	III 964	3174		2045	13.4	9.96	5.2	26	NGC 3144 (d'Arrest)
10 09 16	III 965	**3194**	676	2062	12.9	**10.00**	5.5	28	NGC 3155 (JH Nova)
10 10 11	III 966	**3197**		2065	13.5	**9.90**	10.9	25	
10 12 35	I 283	3218		2081	11.9	10.07	4.7	29	NGC 3183 (d'Arrest)
10 40 52	I 284	3397	733	2218	12.2	10.46	10.0	30	NGC 3329 (JH Nova)
10 54 03	III 967	3465	795	2260	13.5	10.74	6.3	36	trio with III 968, II 904; JH Nova
10 54 03	III 968	3500		2284	13.5	10.78	3.8	35	trio with III 967, II 904
10 59 45	II 904	3523		2302	12.9	10.80	6.5	34	trio with III 967/68
11 28 44	II 905	3752	(917)	2458	12.9	11.33	5.9	38	NF
11 29 07	III 969	3747		2460	15.0	11.33	5.3	36	
11 41 48	III 970	3901		2567	13.7	11.51	7.9	43	
11 46 04	III 971	3939		2598	13.3	11.63	4.2	48	III 940 (sweep 1068) = NGC 3890

Table 3-7: The galaxies of sweep 1096, made on 2 April 1801. They are ordered by sidereal time (ST), referring to the discovery moment. The true AR (α) is for 1800. The next columns give the difference (residual) between Caroline's coordinates and the true ones. The column 'Remarks' shows that some objects were later 'discovered' by John Herschel (JH, h) and d'Arrest; their identity was not recognized by Dreyer.

We now have a perfect fit, but still no explanation for the position differences, which are about 39' on average. Obviously, there is a systematic error, seen in the declination residuals, increasing about the sweep. The key lies in the galaxies NGC 3194 and NGC 3197. According to the true AR, NGC 3197 (9.90^h) must have been seen six minutes earlier than NGC 3194 (10.0^h). But the sidereal time shows the opposite: Herschel saw NGC 3197 about one minute later than NGC 3194! Because of the sweeping method (no looking back in right ascension), this sequence was impossible.

There is only one way to get the correct time sequence: the entire area must be rotated anti-clockwise by about 7°! See Figure 3-13. Such a skewed view can happen, when the telescope, working in the sweep motion, is not exactly in the meridian. In our case (north direction), it is rotated in azimuth to the east by 7°. This setting error is easily explained: the instrument was not correctly turned by the 'round motion' to azimuth 0° for the northern sweep 1096. When applying a tilt correction of 7° to the object coordinates, all position errors immediately disappear!

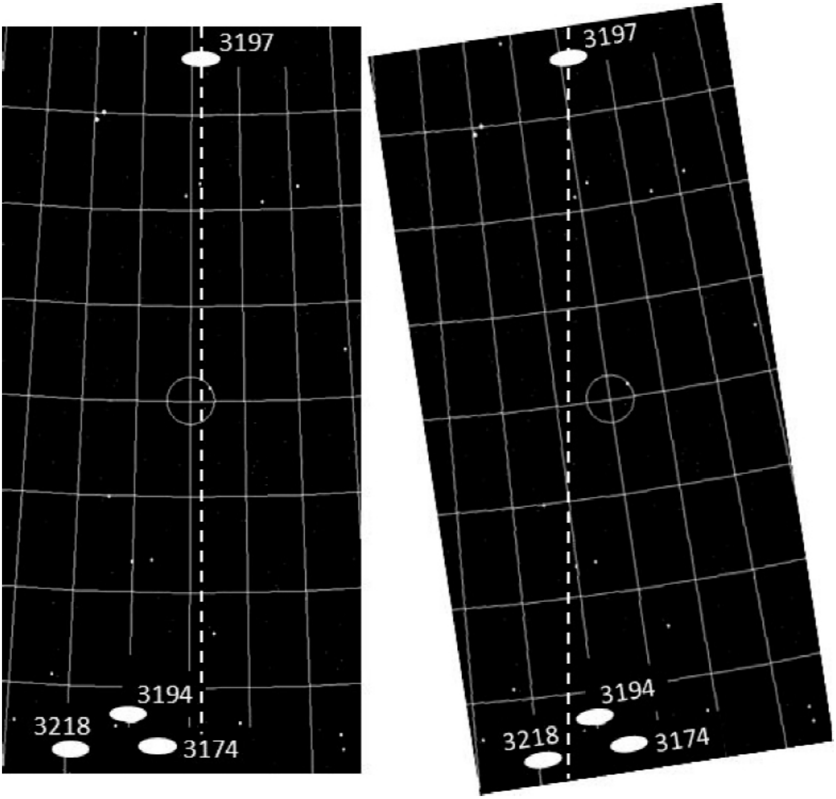


Figure 3-13: Left: Correct sky image. NGC 3197 has a smaller AR then NGC 3194, thus it is seen first (the distance between them is 3.5°). Right: Sky rotated to the left. Now NGC 3197 is seen later than NGC 3194. The strange time sequence is explained by a tilt angle of 7°.

We end up with the following conclusion for the puzzling sweep 1096: the positional errors for the 15 nebulae were caused by two different, independent reasons, which, unfortunately, came together on that night: (1) translation (shift by taking the wrong reference star) and (2) rotation (tilted orientation).

On 5 April, the telescope was still in the wrong setting (the sweep of that night was first numbered '1097'). Again, all objects (two nebulae and five stars), seen in Draco and Camelopardalis, got wrong positions. Because there was no reference star, Caroline did not trust the data and wrote "not to be numbered or registered".

However, applying the described method, all objects can be identified. The two nebulae, both seen “very faint, very small” and verified with 300×, are NGC 3215 (13.2 mag) in Draco and UGC 6728 (14.8 mag) in Camelopardalis. The former has a fainter companion (NGC 3212), which was not recognized.[862] Frustrated Caroline numbered the next sweep, also made on 10 April, ‘1097’. Only two stars were seen, before clouds appeared. After 1801, the second was identified as “196 Camelopardali from Bodes’s Cat.” This identification is doubtful.

To be honest, all authorities (including the author) overlooked William Herschel’s remark, added to the record of the (not registered) sweep 1097: “On examination I find that by an accident of taking down the 25 feet [Spanish] telescope, my instrument has been drawn out of the meridian towards the at least 5 or 6 degrees in azimuth, perhaps more.” The Herschels felt that something was wrong with the northern sweeps 1096-97, but this had no computational consequences – so the drama took its course.

As a precaution, William turned the telescope back to the south for sweep 1098, made on 12 April. Only two known nebulae were seen in Leo. Then, on 11 May, he started the next northern mission. The first sweep (1099) was made above the pole, the following (1100–1106), began only in November, under the pole. The telescope setting was perfect now. In the record for sweep 1100 (8 November), Caroline noted: “Under the pole phenomena are the same as in the south.” This means that the field orientations were the same, independent of the telescope mode (see Figure 2-129).

What happened between May and November? William observed the Sun with small telescopes, and the 20-ft stood idle in the garden. From 13 to 19 June, he visited Alexander in Bath. There the observation of the Sun was continued with a 4-ft Gregorian reflector: “I saw thought the clouds a large opening in the following part of the Sun.” The term ‘opening’ means a sunspot. From 7 to 29 August, William, Mary and John made their usual summer journey to the western England and Wales. The 7-ft ‘skeleton reflector’ was in the luggage; the target again was the Sun. Llangollen, Conwy, Beddgelert, Llanrwst and Llangollen in Wales were visited. Then followed Oswestry, Ludlow, Cheltenham, Burford and Witney in

England (see Herschel's Journeys in the Appendix).

Back in Slough, Herschel received, on 2 September, Piazzi's letter about the discovery of a 'new planet' (Ceres) on New Year's Day 1801. He was requested to observe the object with his superior telescopes. But for this it had to be found first. Already on the 4th, he started a search near the ecliptic with the 7- and 10-foot reflectors, using high magnification. The results were collected in the document 'Review of the Ecliptic by triangles & trapezes etc.', actually a collection of records taken from *Review No. 6*.[863] The last entry is dated 3 January 1802. Herschel searched 49 areas, limited by stars defining the corners of triangles, trapezes or other figures. They did not follow the increasing length of the ecliptic, but were selected for the best views of the respective dates. The 21-night mission did not produce the desired result, although at least 18 double stars were found (N125–42).

The first triangles were inspected on 4 September in Aries. On the 16th, Herschel wrote:[864] "I examined the place south of γ Leonis in order to find whether a planet supposed to exist, and by calculation to be in that neighborhood could be seen. Mr. Piazzi's discovery of a moving star last January gives us room to hope that such a planet may exist." Alas, Ceres was about 10° southeast. On 6 and 9 October, he used the 7-ft at 460×, scanning a trapezoidal area in Leo between the stars γ, η, 42 and 50. Again, he would not be successful. On the first date, Ceres was about 2.1° east of the 50 Leo (Figure 3-14); its daily motion was about 30'. On the 9th, Herschel wrote: "A planet of one tenth of the diameter of Mars, (or a thousand times less) would have been initially perceived." The report of 7 December reads: "New Star. I examined the calculated path of Mr. Piazzi's star from between γ and η Leonis to past β, but saw nothing that with a power of 600 would denote a planetary disk." Ceres was now about 10° southeast of β Leo, still waiting to be found by Herschel.

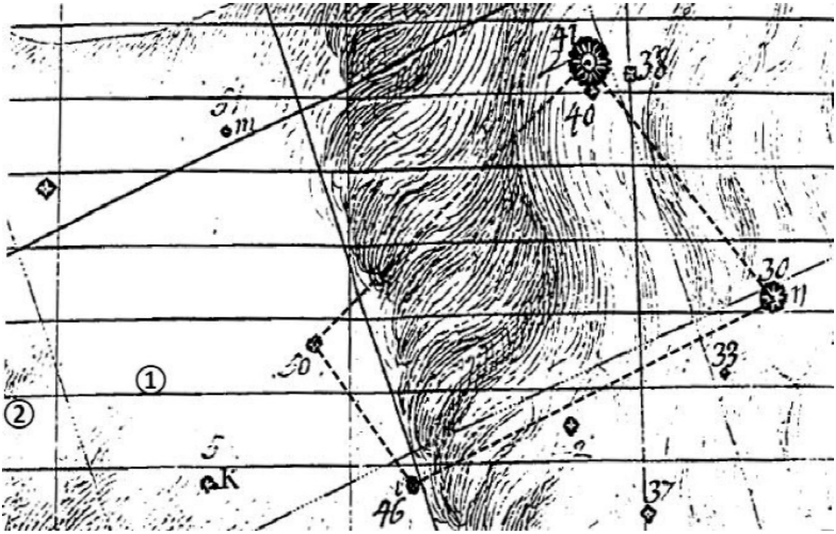


Figure 3-14: Position of Ceres in Leo, marked in the *Atlas Coelestis*: ① = 6 October and ② = 9 October 1801. Herschel searched with the 7-ft in the trapezium γ (40), η (30), 42 and 50 Leo (dashed line).

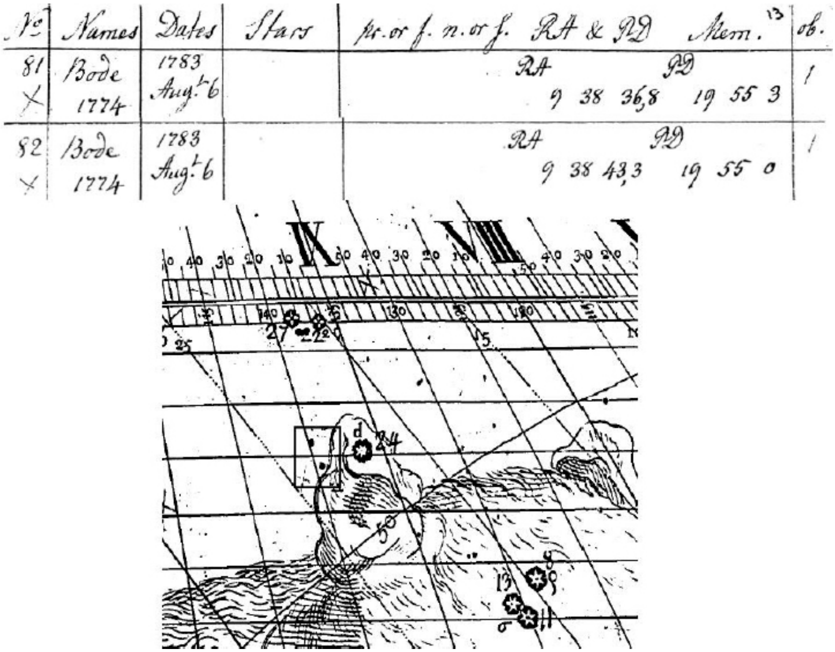
3.3.3. The curious case of M 81/82 and the first asteroids

24 September 1801 saw an important event for the Herschels: Bode's star catalogue and atlas (*Uranographia*), just printed, arrived at Slough. Now Caroline, already engaged in the revision of the sweeps, had access to a large number of reference stars. Although the positions were given for 1801, the necessary calculations were an easy task for her.[865] Bode also played a role in the following case.

On 8 November, sweep 1100 was made in the north, under the pole. Herschel observed two well-known Messier objects in Ursa Major, M 81 (6.9 mag) and M 82 (8.4 mag). The galaxies, separated by 36', were discovered by the Berlin astronomer with a small refractor on 31 December 1774, leading to the name Bode's Nebulae (Figure 3-15).[866] He measured an accurate position, which was taken by Messier for his final catalogue, published in 1781.

William had seen the wide pair only once, on 6 August 1783 with the 12-inch reflector (small 20-ft) at a low altitude of 30°. In 1793, Caroline entered M 81 and M 82 in her list of Messier objects, titled 'Nebulae of the Connoissance des temps' (Figure 3-16).[867] The positions were nearly identical, which was due to the fact that in the early observations they were not measured; occasionally, the place was described in relation to nearby stars or a sketch was made. Caroline plotted both nebulae in the *Atlas Coelestis*; the positions were about 50' too far west. She often had problems converting Messier's coordinates, which were given for the equinox of the date, whereas the Flamsteed atlas used 1690.

Figure 3-15: Bode's sketch of M 81 and M 82, published in his atlas *Vorstellung der Gestirne* of 1782.[868]



No	Names	Dates	Stars	pr. or f. n. or f. RA & PD Mem.[13]	ob.
81 ✗	Bode 1774	1783 Augt 6		RA 9 38 36,8 PD 19 55 3	1
82 ✗	Bode 1774	1783 Augt 6		RA 9 38 43,3 PD 19 55 0	1

Figure 3-16: Caroline's entry of M 81 and M 82 in her table of Messier objects. Only the first observation is listed, made with the small 20-ft (giving very rough positions). Below: The galaxy pair is marked by dots (in the rectangle) in the *Atlas Coelestis*; the places are about 50' too far west.

In 1801 the fascinating galaxies were observed for the first time with the 20-ft. Herschel wrote for M 81, seen first: "Extremely bright, the bright part confirmed to a very small place; the nebulosity is of the milky kind, very much extended from np to sf. It exceeds the limits of the field." Only 36 seconds later and 36' north, he saw M 82: "Extremely bright, much elongated from sp to nf, about 10' long." Right before and after, he found two companion galaxies: NGC 2976 (I 285), 81' southwest, and NGC 3077 (I 286), 46' southeast. They are 10.2 and 9.9 mag bright, respectively. The positions fit well – nothing seemed unusual.

This would change with William's last sweep (1112) on 30 September 1802.869 First, he saw "A very bright, beautiful ray of light, brightest in the middle of all the length. About 8' long; 2 or 3' broad." Another nebula was seen 1.5 minutes later and 38' below:

“Very bright, extremely large, it very nearly fills all the field; it loses itself imperceptibly, much extended from nf to sf. I can trace it nearly ½° in extend beyond the bright part.” Based on these descriptions and the determined positions, we would expect an easy identification as M 82 and M 81, respectively. Astonishingly, this was not the case. Caroline thought the first to be new and catalogued it as GN 2507. For the second she added “No. 82 of the Conoiss. etc.”[870] The reason for the confusion can be explained by the note below the sweep record: “The bubble did not stand right; I therefore by the great motion set the bubble right, and found that the great ropes had shortened so as to raise the telescope 18'. And when the bubble was right as at the beginning the PD clock shewed 17° 9', so that the PD string has shortened 39'.”[871] Obviously, the southern nebula (M 81) was thought to be M 82. Because there was no known object north of M 82, the other must be new. The true declination difference was 37', which is roughly the error calculated from the wrong telescope setting. It is interesting that the positions given in the description were already changed by 26' and 27' respectively, i.e. both nebulae were firstly put half a degree further to the south. These ‘corrections’ had a major consequence: now there were three bright, large nebulae at the ear of the Great Bear!

M 82 was again viewed on 23 December 1805 with the ‘X-foot’: “It is an extended nebula, the length is about ¼ of the field or rather more. It seems to be mottled in the length containing brigthish places like stars.” A last observation of the Messier objects was made on 26 November 1810. Both descriptions matched the galaxies well, but no position was given. There was no word about a third nebula. Herschel wrote:

81 Con [M 81]. I viewed this Nebula with the large 10feet. It has a bright resolvable Nucleus, certainly consisting of 3 or 4 stars or something resembling them. It is about 15 or 16' long. I used the 1st and 2nd powers [eye pieces]; but the object was already too low for being seen in advantage.

82 Con [M 82]. I viewed this nebula also. It is mottled in its length as containing 5 or 6 very small stars affected with nebulosity. With No. 1 about 1/5 of the field or less = about 6 or 7' in length. The breadth is about 1½ or 1¾'. The object is too low.”

Could John untangle the puzzling reports? No, he even increased the confusion. There is an entry ‘h 649’ in the *Slough Catalogue* of 1833, identified with M 82. It is based on an observation, made on 28 October 1831 with his 20-ft: “Extremely bright, extremely large, elongated, position angle 156°; gradually brighter and then suddenly very much brighter middle, with faint rays of light nearly to extremities of field. The most condensed part is 4.1' long and 3' broad.” By the description and position the object clearly is M 81! The true M 82 was not observed.

Next, we have the *Cape Catalogue* of 1847.[872] The relevant part is the appendix ‘Places and Descriptions of Eight Nebulae discovered by the late Sir William Herschel, and not published in his Catalogues’. The list contains objects, designated HON 1 to 8 (‘Herschel omitted nebulae’), found on 30 September 1802 – too late for the third catalogue.[873] The fourth entry of his list (HON 4) is the ‘new’ object of sweep 1112, catalogued as GN 2507 by Caroline. The position (for 1830) is that of M 82. John adopted his father’s description (“A very bright, beautiful ray of light, about 8' long, 2 or 3' broad; brightest in the middle of all its length.”) Obviously, the phrase ‘ray of light’ has moved him to put the object in class IV (‘planetary nebulae’), which now got an extension: IV 79.

GC	h	H	Name	Coordinates (1860)						Description	Obs
1949	649	......	M. 81	9 43 48·9	5·066	1	20 16 10·0	16·70	1	!; eB; eL; E 156°·0; g, svmbMBrN.	4
1950	......	IV. 79 = 4H. ON	M. 82	9 43 52·3	5·142	1	19 34 16·3	16·71	1	vB; vL; vmE “a beautiful ray.”	2*
1951	650	......	....	9 44 0·3	3·497	2	60 7 7·4	16·68	2	F; S; sbM *12; bet 2B st ...	2
1952	3194	......	B. 2686	9 44 1·8	1·975	2	145 45 42·8	16·66	2	Cl; pL; pRi; iF; st 11...12...	2
1953	......	W. H. nova?	M. 81??	9 44 38·0	5·064	1	20 12 18·9	16·73	1	vB; eL; mE; 5 or 6 st (?) inv	1*

Figure 3-17: John Herschel’s helpless treatment of M 81 and M 82 in the *General Catalogue* of 1864.

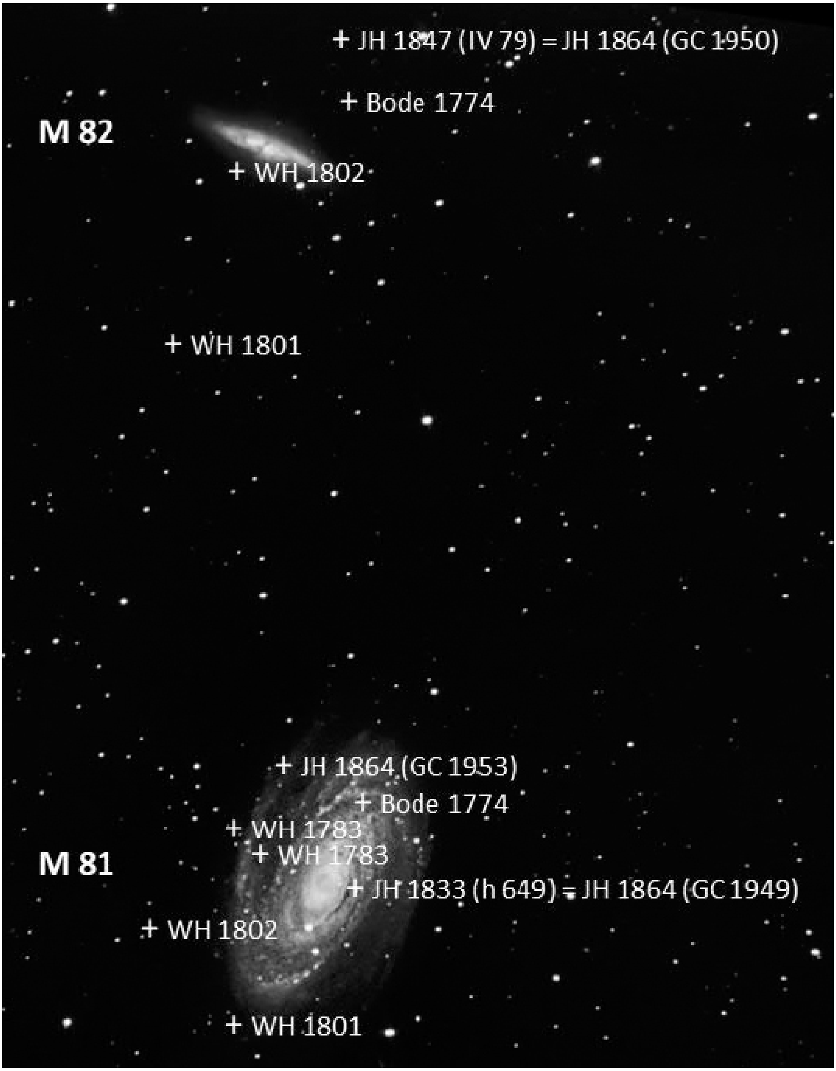


Figure 3-18: Overview of all observations and catalogue positions for M 81 and M 82 due to Bode, William and John Herschel.

The next act in the drama was delivered by John's *General Catalogue* of 1864. Now we actually have three entries: GC 1949, GC 1950 and GC 1953 (Figure 3-17). The first is h 649, now correctly identified as M 81. For the second, GC 1950, we read 'M. 82'. The position is fine too; the description is that of IV 79, given in the *Cape Catalogue*. Obviously, John had realized, that this was M 82.

All questions answered? Unfortunately, not so: the third entry (GC 1953) is still waiting. Here we read 'W.H. nova?' and 'M. 81??'. The position fits to M 81. What has happened? We have to go back to William's notes in sweep 1112 (30 November 1802). John now correctly identifies the 'new' object (no. 2507) with M 82. But the following entry says "No. 82 of the Conoiss." But he had M 82 already on his list (he was not aware, that this is actually M 81). What to do? He was forced to introduce another nebula – this time not an offshoot of M 82 (such as IV 79), but rather one of M 81! What about the description? The *General Catalogue* states: "very bright; considerably large; much extended; 5 or 6 stars (?) involved." In the first instance, the brightness and shape fit both nebulae (M 81 and M 82). But "5 or 6 stars" are mentioned in William's last observation of M 82 (1810) – the same is true for his first (1783). If this is the very source, one may find the reason of John's confusion. The position of M 82 is wrong in Caroline's Messier list of 1793: it is a little east of M 81 – and there we meet GC 1953! John already feared that something was wrong, because in the notes to GC 1953 he stated: "M. 81?? – A nebula observed by W.H. as described, but differing most materially in place from M. 81. It would certainly be very extraordinary should three nebulae so extremely remarkable as M. 81 and M. 82 and this be found to lie so near together." Figure 3-18 shows all positions.

Dreyer solved the problem in the *New General Catalogue* of 1888 as follows: NGC 3031 = GC 1949/53 = h 649 = M 81; NGC 3034 = GC 1950 = IV 79 = HON 4 = M 82. Nowadays all is reduced to the popular M- and NGC-numbers, so nothing is visible of the confusion this beautiful pair of galaxies once brought to the Herschel family.

3.3.4. The last sweeps

Back to 1801. In sweep 1101 on 8 November (the night of William Herschel's first observation of M 81/82 with the 20-ft) an interesting 'planetary nebula' was found in Draco: IV 78.[874] The description reads: "Considerably bright, round, brighter middle, about 1½' in diameter. Somewhat approaching to a planetary nebula with a strong hazy border." This is actually the 11.2 mag galaxy NGC 4750, showing spiral arms wound in a ring, clearly

separated from the nucleus. A similar case is M 94 in Canes Venatici (Figure 3-19).

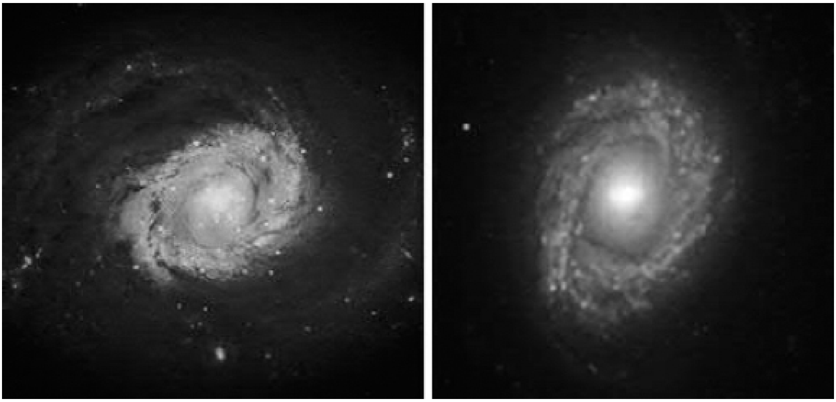


Figure 3-19: ‘Annular’ galaxies, due to ring-like spiral arms: M 94 in Canes Venatici (left) and NGC 4750 in Draco, found on 8 November 1801 and catalogued as ‘planetary nebula’ IV 78 (see footnote 446).

On 7 December (sweep 1105), William found his last object of 1801: the 11.2 mag edge-on galaxy NGC 3735 (I 287) in Draco with an axis ratio 5. He noted: “Much extended, considerably bright, much brighter middle, from np to sf, about 3' long and 1' broad.” The last observations of 1801 were made on New Year’s Eve. Caroline made her debut for the year, viewing her open cluster NGC 6819 in Cygnus (discovered on 12 May 1784) with the large sweeper. William saw it too in the 10-ft. Another target was M 74 in Pisces.

For the Herschels, 1802 was as busy as the previous year. William observed on 108 days, but only seven sweeps were made – the last of his epochal campaign. Caroline made no observations; she was occupied with the compilation of the third catalogue of nebulae and star clusters, to appear later that year (see next section). Most of the time, William observed the Sun and double stars with the 7-ft, to detect a possible orbital motion of the components.[875] However, in the first half of the year he concentrated on the minor planets Ceres and Pallas. In the second half, mainly double stars and the Sun were observed. On 9 November, he watched his second Mercury transit after that of 1786 (see Table 2-54); he used the 7-ft, equipped with

a ‘glass mirror’.876

The first sweep (1106) of 1802 was already made on 1 January. An interesting double galaxy in Ursa Minor was found in a single field: “Two, the preceding considerably faint, small, brighter middle. The following very faint, very small., the place is of the 1st. The 2nd is about 3' more north, and only a few seconds in time following, they being nearly in the same meridian.” Herschel has seen NGC 6251/52 (III 974/75), a 12.5 mag galaxy with a 14.2 mag companion, 2.4' north (Figure 3-20). With a declination of 82° 57', NGC 6252 was his most northerly object (Table 3-8). At this declination it needed eight minutes to cross the standard field of view (see Figure 2-167) – quite a lot of time for a description. However, on 7 April and 19 September 1787, Herschel even had reached the pole in two sweeps (724, 759). Due to incoming clouds and technical problems, both were ‘not registered’. Of course, nothing was found (see Figure 5-7).

δ	NGC	H	Sw	Date	Con	V
82 57	6252	III 975	1106	1 Jan. 1802	UMi	14.2
82 55	6251	III 974	1106	1 Jan. 1802	UMi	12.6
81 15	3057	III 978	1111	26 Sep. 1802	Dra	13.0
81 02	5640	III 949	1074	20 Dec. 1797	Cam	14.7
80 01	1184	II 704	757	16 Oct. 1787	Cep	12.4
80 36	2908	III 977	1111	26 Sep. 1802	Dra	13.3
80 29	5295	III 946	1074	20 Dec. 1797	Cam	14.3

Table 3-8: Herschel objects with the highest declinations (1800), found in the sweeps; all are galaxies. NGC 6251/52 form a pair, distance 2.4' (Figure 3-20).877

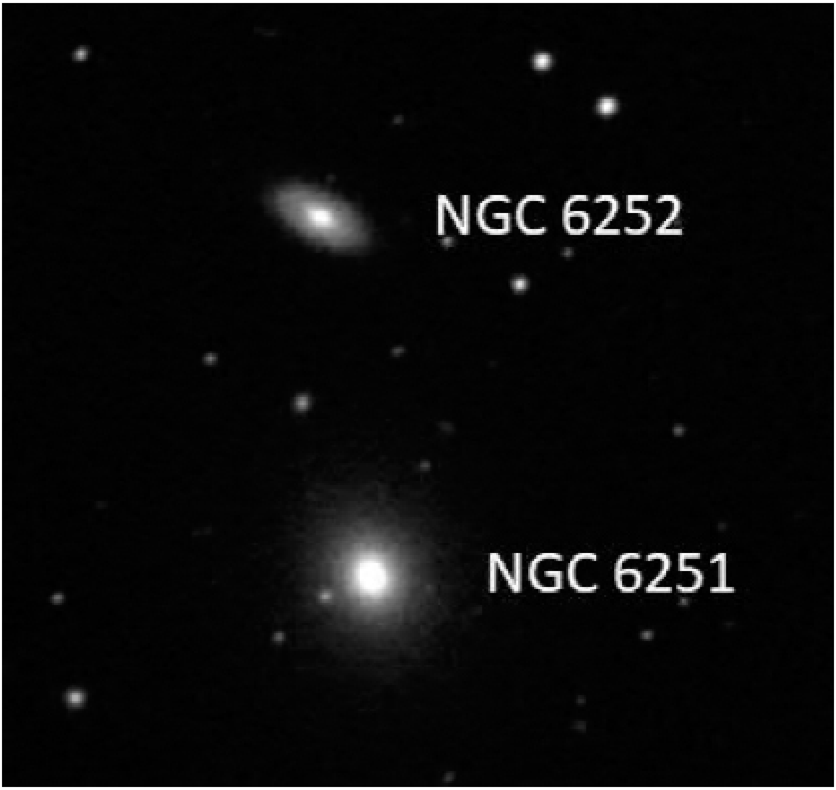


Figure 3-20: Herschel' most northern objects were discovered on 1 January 1802, 40' northwest of ε UMi: the galaxy pair NGC 6251/52 (distance 2.4').

On 13 February, Herschel finally saw Piazzi's 'new planet' Ceres – after eight attempts of autumn 1801. The minor planet had a brightness of 7.6 mag and was located 2.6° southeast of ε Vir:[878]

5h in the morning, 10 feet reflector, Mr. Piazzi's planet shows a very small disk with 600. It is but just with long attention, and alternate comparisons in the finest purest air, to be distinguished from a star of equal apparent magnitude. I estimate the diameter of the Georgian planet, which is in a situation easily to be compared with it, to be from 4 to 6 times that of the former planet. The color of Mr. Piazzi's is ruddy but not very deep. That of the Georgian is blue … Mr. Piazzi's planet is perfectly round, and there is not the least appearance or suspicion of any ring about it.

On 21 April, Herschel saw Pallas, discovered by Wilhelm Olbers on 28 March.[879] He wrote: "Dr. Olbers planet. What I suppose to be the planet by Mr. Aubert's observation of it, has hardly any visible disk." He was not sure that the 7.5 mag object, seen in northern Virgo, was the second minor planet. However, the next night, he saw that it has moved. Herschel wrote a paper, titled 'Observations of the two lately discovered celestial Bodies', read to the *Royal Society* on 6 May.[880] Therein he created the name 'asteroid' for the new celestial bodies: "From this, asteroidical appearance, if I may use that expression, therefore, I shall take my name and call them Asteroids; respecting to myself, however, the liberty of changing that name, if another, more expressive of their nature, should occur."[881] He was led by two properties: appearance (tiny disk) and motion.

On 21 May, sweep 1107 was made in the south, revealing the 13.6 mag galaxy NGC 5789 (III 976) in Boötes. The next sweeps (1108–1110) covered parts of Ophiuchus, Lyra and Aquila. They brought only one object: NGC 6646 (II 907), a 12.6 mag galaxy in Lyra, seen on 26 June in sweep 1109 (see Figure 5-20). It was Herschel's only discovery in the popular constellation, hosting the Ring Nebula M 57 and the globular cluster M 56.[882] On 25 September (sweep 1110), M 2 in Aquarius was viewed with the 20-ft telescope.

On 23 May, Herschel wrote: "Last night [22nd] about half after ten o'Clock we had Jupiter without satellites. Lord Stanhope and Mr. Varley who were with me were much pleased with the uncommon sight."[883]

The final sweeps (1111, 1112) were made on 26 & 30 September, both in the north, under the pole. Sweep 1111 brought six objects. The first, suspected to be a cluster of stars in Camelopardalis, actually is the 10.1 mag galaxy NGC 2655 (I 288). The next discoveries were made in Draco (see Figure 3-24 for all three). With a diameter of 0.8' and a brightness of 13.3 mag, the galaxy NGC 2908 (III 977) is a rather small and faint object. It was followed by the elongated 13th mag galaxy NGC 3057 (III 978). Both are among Herschel's discoveries with the highest declination (see Table 3-8).

Then he found an interesting trio in a single field (Figure 3-21): "Three, the place is that of the last. The last very faint and very

small. The preceding stellar; they are all in a line and about 1' distance from each other. The preceding is the most north, about 2' more than the last." The last two objects of sweep 1111 are the 13th mag galaxies NGC 3212 (III 980) and NGC 3215 (III 981). The latter was already seen in the 'not counted and not registered' sweep 1097 on 5 April 1801. The first object, NGC 3210 (III 979), is only a pair of 14–15 mag stars, 1' northwest of NGC 3212.

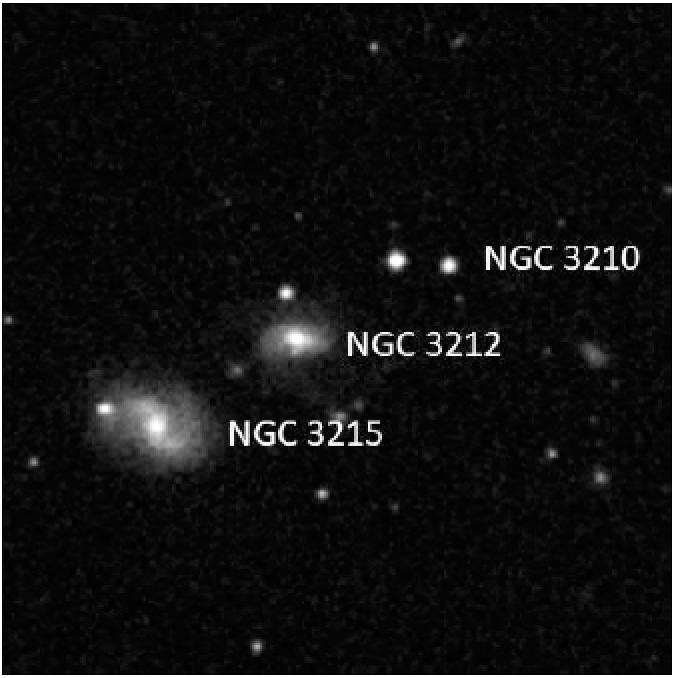


Figure 3-21: NGC 3210 (a pair of 14–15 mag stars) and the pair of galaxies NGC 3212/15 in Draco. The trio was found in sweep 1111 on 26 September 1802 (image 5' × 5').

Sweep 1112 of 30 September brought a final harvest of five new objects, all located in Ursa Major. The first two form a pair, seen in a single field: "Two, the place is of the last. The other precedes it 0,2 fields = 42" and is 6' more north; That of which the place is taken, very faint, small. The preceding one stellar. It is within 1' of a small star which follows it, and which is free from the burs which affect the stellar." All fits well: the star is of 13th magnitude. The galaxies, separated by 12', are NGC 2629 (III 982, 12.2 mag) and

NGC 2641 (III 983, 13.6 mag). Next, the 13.3 mag galaxy NGC 2650 (II 908) was found ("I believe I see some stars, irregularly formed"). Then Herschel saw the 'beautiful ray', later catalogued by John as IV 79 and identical to M 82 (see section 3.3.3).

The final object is curious too: "Three, the place is that of the last, which is faint, pretty large, round. The sp one extremely faint, very small, about 1' more south and 0,1 fields = 20" preceding. The np one pretty bright, stellar, and 0,15 fields = 30" preceding." Caroline noted GN 854, 855 and 2508 in the revised sweep record, indicating that the two former objects were known. Indeed, these were the galaxies NGC 3065/66 (II 333/34), 12.5 and 12.9 mag bright and 2.9' distant, found in sweep 390 (3 April 1785). However, the new object, NGC 3063 (II 909), does not exist. Dreyer places II 909 about 2' west (preceding) of NGC 3066. That explains the lower NGC-number; but this is impossible, because II 909 is definitely the last of the trio. At Dreyer's position we find a close pair of 15th mag stars, which do not appear as "faint, pretty large, round". Because there is no nebula east of the galaxy pair, Herschel's last discovery (II 909) was noted as 'not found' (which is more pleasing than 'non-existent'). The new nebulae of sweep 1112 are shown in Figure 3-22; Dreyer's candidate for NGC 3063 is marked by a circle (x = recorded place). Herschel's last double stars, designated as N144 and N145, were also found.

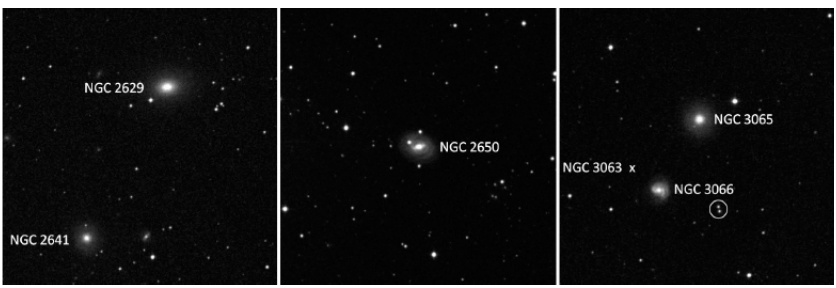


Figure 3-22: Herschel's last non-stellar objects, found in a sweep (see text); all images 10' × 10'.

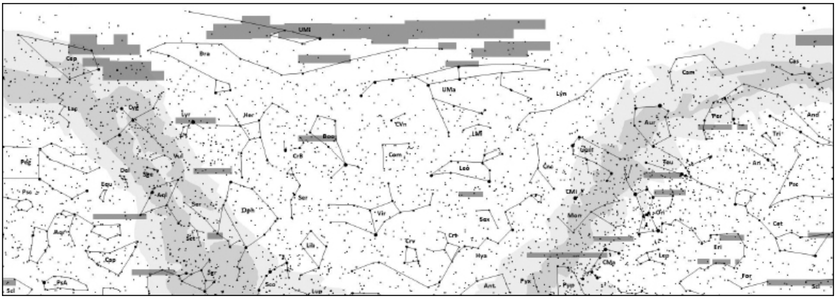


Figure 3-23: Herschel’s sweeps of 1797–1802 (i.e. after the break). Most were made in the north, some in the south.

3.3.5. Summary of 1800–02

Table 3-9 gives the data for the sweeps of 1801 and 1802.[884] 1800 saw only sweep 1093 on 21 January. 1801 started with no. 1094 on 14 January and ended with no. 1105 on 7 December. 1802 started with no. 1106 on 1 January and ended with no. 1112 on 30 September. Sweep 1106 on 1 January 1802 was that with the lowest PD.

Category	1801	Remarks	1802	Remarks
number of nights	10		7	
longest continuous period (days)	2		2	
longest break (days)	358	21 Jan. 1800 – 14 Jan.	140	1 Jan. – 21 May
number of sweeps	12		7	
mean night (hours)	2.2		1.3	
longest night (hours)	5.2	1103	2.0	1111
lowest elevation (°)	20	15 Mar.	36	25 Sep.
highest elevation (°)	80	PD 49°	78	PD 51°
lowest PD (°)	10	6 Dec.	7	1 Jan. (*record*)
observed objects	35		22	
objects per night (mean)	3.5		3.1	
sweeps without objects	2		1	
new objects (all)	23		15	
uncatalogued objects	-	Table 5-5	8	
re-observed objects	12		7	
most productive night	2 Apr.	15 objects	30 Sep.	12 objects
first object		NGC 1055 (Gx Cet)		NGC 6251 (Gx UMi)
last object		NGC 6819 (OC Cyg)		NGC 3077 (Gx UMa)
brightest object (mag)	9.9	NGC 3077 (Gx UMa)	8.4	M 82 (Gx UMa)
faintest object (mag)	15.0	NGC 3747 (Gx Dra)	14.2	NGC 6252 (Gx UMi)
smallest object (")	30	NGC 3747 (Gx Dra)	42	NGC 6252 (Gx UMi)
discovered multiple systems	1	pair	1	pair
observed Messier objects	2		3	
new double stars	2		-	
star gages	2		-	

Table 3-9: Sweep statistics for the years 1801 and 1802 (there was only one sweep in 1800). No new garnet stars or vacant places were seen.

In 1800, William's papers on the 'power of penetrating into space' and the thermal radiation (infrared) were published. Caroline stayed four months at Bath. 1801 was the year of the 'mystery sweep' 1096. William made a summer tour of Wales/England, lasting 23 days. Piazzi's letter about Ceres arrived and a search near the ecliptic (Review) was started. Bode's *Uranographia* was received. In 1802, William saw Ceres and Pallas. He also watched his second transit of Mercury. The third catalogue of nebulae and clusters was published and Caroline created her 'Catalogue of 2500 Nebulae and Clusters'.

3.4. The final catalogue of nebulae and star clusters

3.4.1. Three missing objects

On 1 January 1802, when two nebulae were found in sweep 1106, NGC 6251/52 (III 974/75) in Ursa Minor, Caroline's 'General number' (GN) reached 2500. William thought that it was time for a third catalogue, although it would contain 'only' 500 new non-stellar objects. Of course, 1000 was out of reach. The siblings were exhausted from the immense task and meanwhile had other interests. As usual, the compilation was derived from Caroline's 'General catalogue', which was brought into eight class tables. Fortunately, we have the resulting manuscript, titled 'Catalogue of 500 additional new Nebulae and clusters of Stars'.[885] It still shows a GN column.

Although the manuscript does not mention a date, it must have been finished before 21 May. On that date, sweep 1107 brought a new nebula (III 976 = NGC 5789 in Boötes). It obviously was squeezed into the space at the end of the table for class III; separating lines indicate this (Figure 3-24). Another nebula was discovered on 26 June in sweep 1109 (II 907 = NGC 6646 in Lyra, see Figure 5-20). It was added at the end of class II. Caroline made a fair copy of the manuscript, now including William's introduction; his text covers 25 pages and treats various kinds of non-stellar objects. The *Royal Society* has archived the original, titled 'Catalogue of 500 new nebulae, with remarks on the construction of the heavens'.[886] The manuscript is dated 29 June 1802 and was read to the Society on 1 July.

When the Herschel family started a tour of France on 13 July, Caroline found time to continue her work on the revision of all sweeps, taken from the 'original' records.[887] In the new document, every non-stellar object got a 'General number'. Until August, she revised the data of sweeps 900 to 1109, noticing three critical entries:

- GN 2131 of sweep 924 (17 April 1789) is GN 1960 (II 757), found on 5 May 1788 (sweep 842),
- GN 2159 of sweep 929 (26 April 1789) is GN 2089 (II 797), found on 14 April 1788 (sweep 921),
- GN 2191, found in sweep 948 on 17 March 1790 does not

exist.

This led to a revised 'General catalogue' – it now ended with number 2497! Caroline also corrected her manuscript and added – for control – a new first column, showing the revised numbers. Because three entries were lost, another sweep was urgently needed to get back to GN 2500!

The sweep was made on 25 September (sweep 1110). Alas, nothing was found. The search for new objects was continued. Already the next night (sweep 1111) brought relaxation when Herschel saw three unknown nebulae. They were catalogued I 288, III 977 and III 978 and numbered GN 2498–2500. The first is the 13.3 mag galaxy NGC 2655 (10.1 mag) in Camelopardalis; the two others are the galaxies NGC 2908 and NGC 3057 in Draco with 13.3 and 13.0 mag; the latter is of the 'magellanic' type. All three are seen in Figure 3-24.

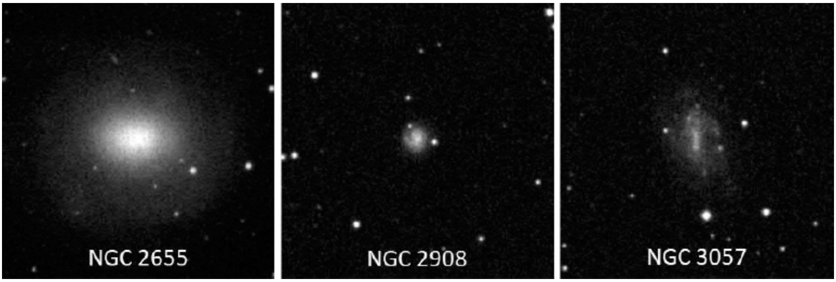
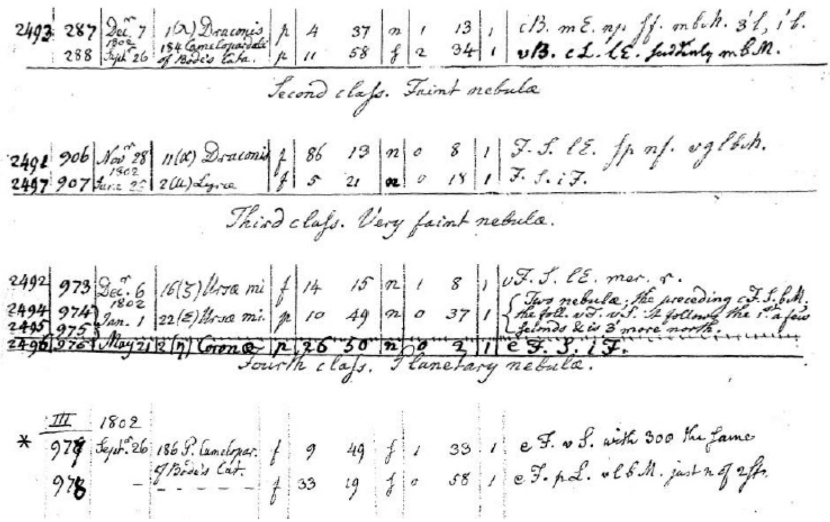


Figure 3-24: These three galaxies were found on 26 September 1802 (sweep 1111) to again reach GN 2500 (see text).

Caroline added the three new objects to her draft manuscript (Figure 3-25). I 288 was entered below the 'First class' table, the other two (III 977, III 978) below the last table, because there was not enough space after that of the 'Third class'; there we find already III 976 (NGC 5789) in Boötes, found on 21 May.

A revised catalogue was soon sent to the *Royal Society* (now without 'General numbers'). On a separate piece of paper, Caroline informed the editor about the necessary changes to the manuscript: "And in the third class of very faint nebulae add the two following, at the end." The data of III 977/78 followed. Then she explained:[888] "The

reason for the addition is that, on casting up, the number of nebulae were found to be less than 500." Her instructions are shown in Figure 3-26.

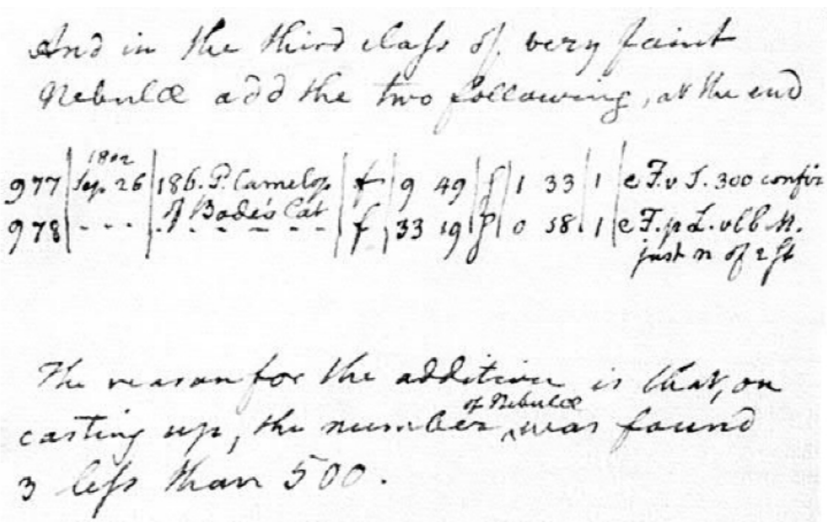


Second class. Faint nebula

Third class. Very faint nebula.

Fourth class. Planetary nebula.

Figure 3-25: Caroline's draft of the third Herschel catalogue with inserted new objects (see text).



And in the third class of very faint Nebulae add the two following, at the end

977	1802 Sep. 26	186. P. Camelop. of Bode's Cat	f	9	49	f	1	33	1	e F. v S. 300 confir
978	- - -	- - - - -	f	33	19	f	0	58	1	e F. p L. v l b M. just n of 2 ft

The reason for the addition is that, on casting up, the number of Nebulae was found 3 less than 500.

Figure 3-26: Caroline's piece of paper with instructions for the editor concerning the three new entries (see text).

Herschel’s third (and final) catalogue of non-stellar objects was eventually published as the last paper in the ‘June issue’ of the *Philosophical Transactions* for 1802, which appeared in December.[889] It was titled ‘Catalogue of 500 new Nebulae, nebulous Stars, planetary Nebulae, and Clusters of Stars; with Remarks on the Construction of the Heavens’.

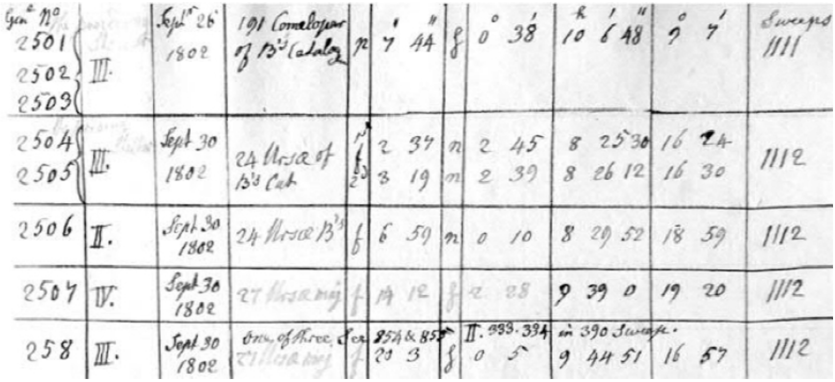
3.4.2. Dates of the three catalogues and the eight additional non-stellar objects

Table 3-10 gives the dates of the first/last observations, included in the three Herschel catalogues. Note the late final date for the first catalogue (see section 2.4.1).

Cat	Date	Sw	GN	H	NGC	Con	V	Ref star	V*	Remarks
1	18 Dec. 1783	47	11	II 6	-	Cet		82 δ Cet	4.1	2 stars
	24 Oct. 1786	621	576	II 239	1161	Per	11.0	27 κ Per	3.8	pair w. NGC 1160
2	26 Apr. 1785	402	1001	III 377	3837	Leo	13.3	92 Leo	5.3	in Abell 1367
	23 Mar. 1789	917	1756	IV 49	5507	Vir	12.5	102 υ1 Vir	5.1	
3	3 Dec. 1788	889	2001	III 748	2366	Cam	11.1	43 Cam	5.1	+ NGC 2363
	26 Sep. 1802	1111	2500	III 978	3057	Dra	13.0	186 P Cam (Bode)	4.3	Figure 3-24

Table 3-10: Dates of the first/last observations in Herschel’s three catalogues of nebulae and star clusters.

What about the eight other finds of sweep 1111 and 1112? Though numbered GN 2501–08 by Caroline, the new objects were not added to the third catalogue. Of course, 508 entries were unwanted! However, they were listed in the ‘General catalogue’ with positions for 1790. The table was expanded (see ‘turn over’ in the lower right corner) to cover 80 pages now. Astonishingly, the eight added objects do not appear in her *Zone Catalogue*.

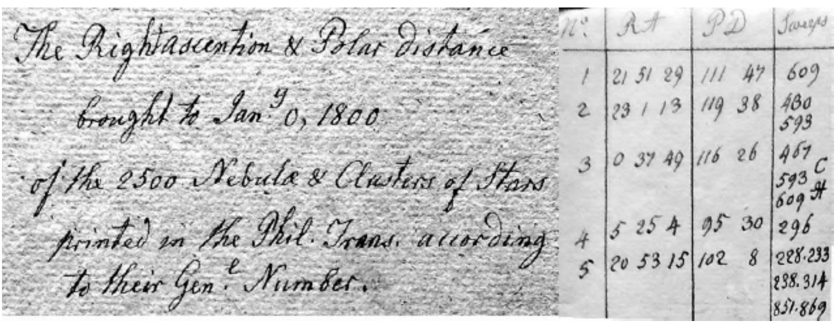


Genl No									Sweeps
2501 2502 2503	III	Septr 26 1802	191 Camelopar of B's Catalog	p	7 44	f 0 38	10 6 48	9 7	1111
2504 2505	III	Sept 30 1802	24 Ursa of B's Cat	p f	2 37 3 19	n 2 45 m 2 39	8 25 30 8 26 12	16 24 16 30	1112
2506	II.	Sept 30 1802	24 Ursae B's	f	6 59	n 0 10	8 29 52	18 59	1112
2507	IV.	Sept 30 1802	27 Ursae maj	f	14 12	f 2 28	9 39 0	19 20	1112
258	III.	Sept 30 1802			854 & 855 20 3	II. 333. 334 in 390 Sweeps. f 0 5	9 44 51	16 57	1112

Figure 3-27: The additional objects GN 2501–08, found in sweep 1111–12 on 26 and 30 September 1802, are listed in Caroline's 'General catalogue' with positions for 1790 (left of the last column).

At the end of 1802, Caroline's work on the sweep records was finished. The document contained:

- objects numbers (GN 1–2508)
- positions for the unique equinox 1800 (instead of 1690, 1785 and 1790)
- new reference stars (from Bode's catalogue)
- unknown stars (U)
- new double stars (N)



The Rightascention & Polar distance brought to Jan. 0, 1800 of the 2500 Nebulae & Clusters of Stars printed in the Phil. Trans. according to their Genl. Number.

No.	RA	PD	Sweeps
1	21 51 29	111 47	609
2	23 1 13	119 38	480 593
3	0 37 49	116 26	467 593 C 609 H
4	5 25 4	95 30	296
5	20 53 15	102 8	228.233 238.314 851.869

Figure 3-28: Caroline's table of '2500 Nebulae and Clusters of Stars' with positions for 1800.

Based on the sweep revision, Caroline created a new table: 'The Right ascension & Polar distances brought to Jan. 0, 1800 of the

2500 Nebulae and Clusters of Stars printed in the Phil. Trans. According to their Gen. Number'. The objects GN 2501–08 were added. It was finished in spring 1804, shortly after her work on the revised sweep records had ended on 16 March 1804. The table, covering 23 pages, had only four columns: number (GN), AR, PD and sweep (Figure 3-28). The last column gives – for the first time – all sweeps in which an object was seen, replacing the column 'Obs.' in the three catalogues. The given position was that of the discovery sweep.

In 1847, John presented the eight additional Herschel objects in his *Cape Catalogue* (Table 3-11). The table (in the appendix) was titled 'Places and Descriptions of Eight Nebulae discovered by the late Sir William Herschel, but not published in his Catalogues'.890 The entries, designated as HON 1 to 8 ('Herschel omitted nebulae'), were sorted by right ascension for 1830. Although Caroline had already defined a class for each object in the 'General catalogue', John added the accompanying serial numbers (see column 'H').

NGC	GN	H	Sw	Date	V	Con	Type	HON	Remarks
3210	2501	III 979	1111	26 Sep.1802	14.2	Dra	star	6	trio
3212	2502	III 980	1111	26 Sep.1802	13.2	Dra	Gx	7	trio
3215	2503	III 981	1111	26 Sep.1802	13.1	Dra	Gx	8	trio; 5 Apr. 1801 (1097)
2629	2504	III 982	1112	30 Sep.1802	12.2	UMa	Gx	1	pair; Figure 3-22
2641	2505	III 983	1112	30 Sep.1802	13.6	UMa	Gx	2	pair; Figure 3-22
2650	2506	II 908	1112	30 Sep.1802	13.3	UMa	Gx	3	Figure 3-22
3034	2507	IV 79	1112	30 Sep.1802	8.4	UMa	Gx	4	M 82, 6 Aug. 1783
3063	2508	II 909	1112	30 Sep.1802		UMa	NF	5	trio with III 333/34; Figure 3-22
7810	-	III 984	320	17 Nov. 1784	13.0	Peg	Gx	-	H. MS., h 2296; in *Zone Catalogue*
4646	-	II 910	1001	2 Apr. 1791	13.4	UMa	Gx	-	II 794,2
4695	-	III 985	1001	2 Apr. 1791	13.5	UMa	Gx	-	[II 796]

Table 3-11: Objects found in sweep 1111 and 1112, catalogued with GN > 2500 and not included in the third catalogue. HON = 'Herschel omitted nebulae', referring to John's table in the *Cape Catalogue*. Also listed are three uncatalogued objects, listed in Dreyer's revision of the Herschel catalogues (*Scientific Papers*); H.MS. = 'Herschel manuscript' (according to John).

In the *Scientific Papers* of 1912, Dreyer presents a revised version of the three Herschel catalogues (see section 6.4). Of course, a new column 'N.G.C.' was added. The class tables were expanded by the eight additional Herschel objects, according to John's designations. However, another three objects were inserted, found by William,

but not jet catalogued. Dreyer designated them II 910, III 984 and III 985 (see Table 3-11 and Table 5-5).

3.5. The post-sweeping era: 1803–1822

3.5.1. A revival of Messier objects and Herschel's new favourite, the 'X-foot'

The end of the sweep campaign did not mean turning away from non-stellar objects. But William's focus changed to the Solar System. Also Messier objects again became interesting targets. The *Reviews*, continued in 1800, were the only remaining document series. They contain all kinds of observations: Sun, planets, single/double stars, Messier objects and a few nebulae and star clusters from the Herschel catalogues. However, no further discoveries were made in the realm of non-stellar objects. It was John, who in August 1823 discovered the first after William, following a break of more than 20 years.

In 1803, William observed on 57 days; there were no observations by Caroline.[891] He viewed double stars and the Sun. Only three non-stellar objects were observed: M 42, M 11 and M 15. On 3 April, Jupiter was shown to "Dr. Wilson and the Rev. Mr. Jones from Cambridge".[892] They saw the shadow of its 1st satellite on the planet. On 26 September, an illustrious party viewed the 70% illuminated Moon in the 40-ft at about 8:00 pm. Herschel wrote: "I viewed the Moon but found it so bright that I did not look long for fear of injuring the eye. General Richardson and about 10 Ladies saw it; its altitude [18°] being very convenient for amateurs."[893]

Document	Period	RAS	Remarks
Review No. 5	14 Feb. 1792 – 31 Jan. 1800	W.2/2.5	
Review No. 6	4 Feb. 1800 – 1 Sep. 1802	W.2/2.6	Review of the Ecliptic
Review No. 7	4 Sep. 1802 – 25 Sep. 1810	W.2/2.7	
Review No. 8	30 Sep. 1810 – 4 Jul. 1819	W.2/2.8	RAS scan shows wrong order

Table 3-12: The final *Reviews* are stored in the Herschel Archive of the *Royal Astronomical Society* (RAS).

On 11 February 1804, Herschel watched his third partial solar

eclipse (see Table 2-54): “I had prepared the 7 and 10 feet telescopes but the weather was raining and cloudy, A few moments from the beginning I had a good view of the Sun; and about a minute after the beginning I got an other glimpse of it.” On 13 March, he saw Venus with the 10-ft at 400×: “extremely distinct, there is no spot on the disk of the planet”. Then the ‘large 10 feet’ was used for an interesting experiment: “Light. I tried to read the title page of the Phil. Trans. By the light of Sirius brought to the focus; but did not succeed; the focus of the star being too small, and when the back was removed to diverging rays, the light was not strong enough.” Until September, the Sun and double stars were observed.

Between 21 June and 28 August, Herschel was concerned with the brightest stars: Sirius, Arcturus, Capella, ‘Lyra’ (Vega), Rigel, Betelgeuse, Procyon and Aldebaran. The reason was a new attempt to determine the direction of the solar motion in space; the target point on the sphere is known as the ‘solar apex’. The case had already been treated in 1783, finding that the Sun moved towards λ Her (4.4 mag). Now Herschel made another investigation, based on new proper motion values. The result was published in the *Philosophical Transactions* for 1805 as ‘On the Direction and Velocity of the Motion of the Sun, and Solar System’.[894] Generally, he confirmed the earlier result.

On 23 September, Herschel tried to see “Mr. Harding’s new Asteroid” in Pisces, found on the 1st by Harding at Lilienthal and later named Juno. In the next nights, he searched in vain again, but was finally successful on the 29th: “10 feet Reflector power 527. It has the appearance of a small star.” The third asteroid was seen in Cetus with 7.7 mag; it was observed until 26 November. Herschel wrote a paper about Juno, which was read to the *Royal Society* on 6 December and published in 1805.[895] In total, William made 57 observations in 1804, Caroline none.

On 19 February 1805, Herschel made naked-eye observations of the Milky Way to find structures and their connection to bright stars (this issue was continued in 1813). In April and May, Saturn and Jupiter were viewed, occasionally with the 40-ft and the X-foot.

The X-foot and 40-ft were mainly used after the sweep

campaign.[896] The X-foot was equipped with four eye-pieces, offering various magnifications and fields of view: No. 1: 71 × (36'), No. 2: 108 × (24'), No. 3: 171 × (9'), No. 4: 220 × (7'). But there was another ‘special telescope’, the 25-ft reflector, built for Charles IV, King of Spain. Here are the data of the three telescopes (compare Table 3-6):

- X-foot (‘large 10-feet’): Newtonian, aperture 24 inches, used 24 Aug. 1799 – 15 Nov. 1811
- 25-ft (‘Spanish telescope’): front-view, aperture 24 inches, used 24 Jan. 1797 – 1 Apr. 1801
- 40-ft: front-view, aperture 48 inches, used 20 Nov. 1787 – Aug. 1814

In autumn, Herschel’s focus was on Messier objects. Inspired by the light-gathering power of the X-foot, he viewed 24: M 1, M 2, M 13, M 15, M 27, M 29, M 31–33, M 36–38, M 52, M 56, M 57, M 71, M 72, M 74, M 76–78, M 82, M 92, M 97. During this mission, the 11.5 mag galaxy NGC 1003 (II 238) in Perseus, found on 6 October 1784 (sweep 283), was accidentally seen on 13 November: “Looking at the 34th of the Connoiss. I saw by mistake my own nebula. The brightest part of it is very small. It has a resolvable nucleus with very faint extensive branches. With 0,75 inch glass the branches extend beyond the field of view.” NGC 1003 is 2° southwest of M 34.

Table 3-13 collects the objects observed with the exceptional reflectors (35 Messier, 15 NGC, 1 IC); M 42 was viewed six times (compare Table 3-14). The only discoveries in that period were the galaxies NGC 4831 (Hydra), NGC 7441 (Aquarius) and IC 1339 (Capricornus); the 40-ft finds were not catalogued (see Figure 2-174). The galaxy pair NGC 2992/93 in Hydra was the only non-stellar object, ever observed with the 25-ft.

Tel	Date	Objects
X-ft	24 Aug. 1799	M 75
	28/29 Aug. 1799	M 3, M 11, M 15, M 31, M 72, M 75, NGC 869/84 (VI 33/34), NGC 7009 (IV 1)
	2/3 Sep. 1799	M 2, M 13, M 15, M

		31, NGC 7009 (IV 1), NGC 869/84 (VI 33/34), NGC 7009 (IV 1), NGC 7662 (IV 18)
	14 Jan. 1801	M 42, M 43, M 77
	14 Aug. 1803	M 11, M 15
	20 Nov. 1805	M 77
	22 Nov. 1805	M 13, M 92
	23 Nov. 1805	NGC 1003 (II 238), M 13, M 15, M 36–38, M 56, M 57, M 71, M 74
	3 Dec. 1805	M 2
	9 Dec. 1805	M 2, M 33, M 77
	17 Dec. 1805	M 29
	23 Dec. 1805	M 1, M 27, M 31, M 32, M 52, M 78, M 82, M 97
	13 Jan. 1806	M 79
	11 Feb. 1806	M 42
	1 Jan. 1807	NGC 7662 (IV 18), M 56, M 77
	21 Sep. 1810	M 11
	24 Sep. 1810	M 3
	25 Sep. 1810	NGC 7009 (IV 1), M 33, M 72
	30 Sep. 1810	M 28, M 30
	3 Oct. 1810	M 2, M 11, M 15, M 22, M 26, M 75
	4 Oct. 1810	M 74
	30 Oct. 1810	M 72
	26 Nov. 1810	M 81, M 82
	19 Jan. 1811	M 31, M 42
25-ft	12 Mar. 1798	NGC 2992/93 (III 277/78)
40-ft	19 Feb. 1787	M 42
	27 Aug. 1789	NGC 7392 (II 702)
	28 Aug. 1789	**NGC 7441**
	11 Sep. 1789	NGC 7585 (II 236)
	20 Oct. 1789	NGC 779 (I 101)
	27 May 1791	M 5

	29 Sep. 1791	**IC 1339**
	8 Sep. 1792	NGC 7009 (IV 1)
	9 Apr. 1793	**NGC 4831**
	4 Sep. 1799	M 2
	28 Dec. 1799	M 74
	11 Jan. 1810	M 42
	30 Oct. 1810	M 72
	19 Jan. 1811	M 42
	29 Jun. 1813	M 72

Table 3-13: Exceptional reflectors and the non-stellar objects observed with them (bold = discoveries).

The non-stellar objects, observed with the 40-ft, had a maximum elevation of 53° in the meridian (M 74 in 1799). A little higher were Uranus and Saturn at 58° (1790) and 61° (1801), respectively. It appears that Herschel avoided elevations above these values, even though the mounting of the heavy telescope was prepared for it; there was a sophisticated bar mechanism (see Figure 2-7, inset).[897] Adding all observations, the 40-ft was used in just 44 nights over a period of 27 years (19 February 1787 to August 1813); most of them on planets. Lalande wrote in his annual 'History of Astronomy' for 1806 that the 40-ft was a total failure, not making any spectacular discovery.[898]

On 8 December 1805, William saw a comet: "I discovered a Comet in the constellation of Aquarius. It is about 4 degrees south following Fl 100 [100 Aqr], making nearly an equilateral triangle with 100 and 107. In my large 10 feet telescope [X-foot] the coma extends so as take up a space of at least 20'. It has a confused, but not determined nucleus." On the following day, he wrote a note to Caroline: "Lina. Last night I popt [popped] upon a Comet. It is visible with the naked eye between Famalhaut [Fomalhaut] and β Ceti, but above the line that joins the two stars. It made an equilateral triangle (downwards) with 100 and 107 Aquarii. I wrote last night to Sir J. Banks and write now also to Dr. Maskelyne. Adieu."[899] However, the comet had already been found on 10 November by Pons.[900] In summary, William made observations on 36 days in 1805; again, Caroline on none.

Nearly the same situation appeared in 1806. William's observations,

however, decreased to 28 days. Though the Messier objects M 35, M 42 and M 79 were viewed with the 10-ft in January/February, his main target was Saturn. On 16 June, he watched his fourth (and last) solar eclipse (see Table 2-54), though, like all others only a partial one ("it was very beautiful"). On 9 July, William noted: "I showed my brother Johann Dietrich Herschel from Hanover Saturn, and the air happening to be very clear he saw all the phenomena on the planet in perfection."

The astronomical year 1806 ended on 30 December with 10-ft observations of some nebulae and star clusters. The first seemed to be new: "There is a cluster of very small stars preceding 19 Cygni & in a line between γ Cygni and η Lyrae." But this was Caroline's NGC 6819, discovered on 12 May 1783 with the small sweeper. Next, M 57 was viewed ("A very curious object, with its black vacancy."), then the bright planetary nebula NGC 1535 (IV 26) in Eridanus followed, found on 1 February 1785 (sweep 364). William guessed it to be "a cluster of stars at a very great distance". The last object was M 43, offering an interesting idea: "The star in this nebula does not appear to be connected with it. It is neither in the middle of it, nor is there any condensation near the star. It is therefore not what I call a nebulous star." This is the variable star NU Ori, showing a mean brightness of 6.8 mag.

On 1 January 1807, the tour of non-stellar objects was continued with the X-foot, equipped with eye-pieces No. 3 & 4. Herschel viewed M 56, M 77 and the planetary nebula NGC 7662 (IV 18) in Andromeda. The planetary nebula NGC 6894 (IV 3) in Cygnus was not found until the 20-ft was used on the 3rd. Two days later, he observed M 56 and M 71, and on 10 January M 15 with his standard reflector.

On 27 January, Caroline was back from an observing break of five years! She watched a comet with her large sweeper: "I brought this morning a memorandum with me from Windsor, which I copied from the Hamburgher papers at the Castle." The popular German newspaper *Hamburgischer Correspondent* informed her about a comet, discovered on the 15th by Pons; positions for some dates were given. She wrote: "This being a part of the heavens which I could get sight of at the house at Upton, I took my sweeper down in

the Garden and began to sweep as soon as daylight was gone." Unfortunately, the 7th mag object was only 6° above the south-western horizon in Sculptor. Nevertheless, Caroline was successful: "It is one of the smallest comets I have seen, but not the smallest and would undoubtedly have appeared to be very considerable if it would have been observed at a higher altitude; for it was actually setting at the time I was looking. It appears like an oblong nebula rounded at the corners shaped like an egg." The next night, "I had my sweeper carried to Slough, and went there with the intention of showing the comet to my brother, but the heavens were totally overcast." The bad weather continued until 31 January, when the siblings could eventually observe the comet, now located at the border of Cetus. William saw it again in the next night with the 10-ft, though for the last time.

On 5 and 6 April, William was visited by "Miss Baillie & her sister Joanna, the author of several volumes of dramatic pieces".[901] Jupiter, Saturn, Uranus and the Sun were presented.

A fourth asteroid entered the scene at Slough on 20 April: Vesta, discovered on 29 March by Wilhelm Olbers (his second one after Pallas). After unsuccessful attempts to find the object, made in eight nights, Herschel wrote on 22 May about a possible candidate: "It has moved from its place last night … It is of about the eighth magnitude. The star A marked on April 24 was the Asteroid." Vesta (6.0 mag) was now 2° northeast of δ Vir. William followed it with the 7-ft until 3 June (the daily motion was about 5').

On 18 August, the Dukes of Kent and Orléans were guests of Caroline.[902] However, the star party only followed in October, when the people made a pilgrimage to Slough to see the showpiece of the year: the Great Comet of 1807, discovered in Sicily on 9 September. Caroline first saw it on 2 October:

Yesterday my Nephew G. Griesbach sent me word that there was last night Sept. 30 a very large comet visible towards the West, in consequence of this information I opened a letter which I received the 29th for my Brother a few hours after he left home for a few days. By this letter I saw that Mr. Pigott had seen the comet on the 28th and he sent my brother his observations etc. Last night it was totally cloudy but this evening at about 6^{h} 10' I saw it very plainly

with the naked eye after watching sometime for the removal of the clouds.[903]

The comet, placed at the Serpens/Virgo border, had a brightness of 1.5 mag. William first observed it on 4 October, joined by illustrious guests. Caroline wrote: “Count Münster, General Cartwright, Mrs. Beckedorff & Miss Beckedorff saw the comet.”[904] On the 7th, James Lind and his eldest daughter saw the comet and on the 14th a crowd of more than 50 people besieged the Slough observatory, among them Prince Augustus Frederick, the Duke of Sussex.[905] On the 19th Caroline noted: “The Bishop of Salisbury, Lady F. Mury and Lord Lewsham, 2 Lady’s Strangways etc. saw the comet.”[906] The Great Comet of 1807 was the main target of the siblings for the rest of the year. On 24 October, Caroline made a sketch (Figure 3-29).[907] The object was followed by William until 21 February 1808. There was a final observation of the Moon, made on 8 November. In total, William observed on 55 days in 1807; Caroline on seven.

There is remarkable gap in Caroline’s observations. There is no entry between 24 October 1807 and 1 September 1811 (see Figure 5-29). What caused the long break? It could be due to problems with her eyes. In 1808, the family doctor (Dr Phips) had feared she was going blind, but on 20 November 1809 we read: “Phips pronounced me out of danger from becoming blind, which he ought to have done much sooner, or rather not to have put me unnecessarily under such dreadful apprehension.”[908] Anyway, all seemed to be fine in autumn 1811.

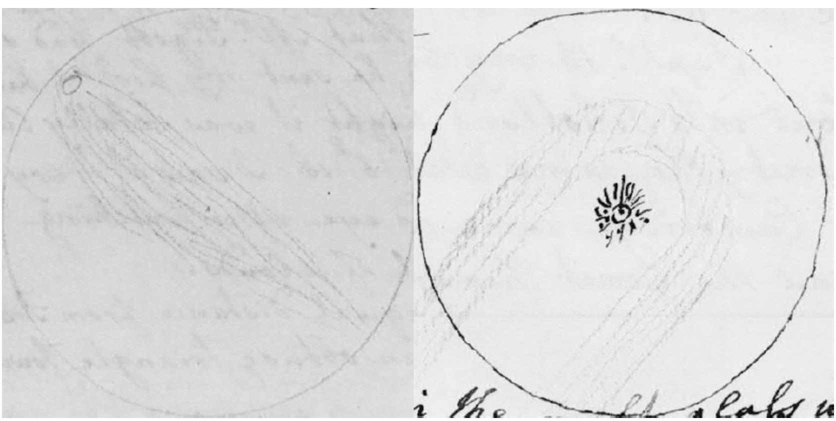


Figure 3-29: Caroline sketched the Great Comets of 1807 and 1811. Left: 24 October 1807 with the 'night glass'; right: 8 September 1811 with the large sweeper.

After the Great Comet of 1807 had gone, Herschel was visited by the Duke of Cambridge on 3 February 1808; he was interested in the 40-ft reflector.909 In May/June, he inspected Saturn and Uranus; then the window for Vesta opened again. The asteroid was viewed 10 times between 8 and 21 September. Also Ceres was seen on a few nights. This closed the year 1808, which saw observations by William on 42 days.

In 1809, Herschel mainly monitored the Sun; only a few observations concerned planets. On 12 January, he saw Jupiter for the last time, using the 7-ft. On 28 & 30 December, he observed M 1, M 67 and M 77 with the 10-and 20-ft reflectors. The number of observing days was 25.

1810 was a 'Messier year'. It started on 11 January with M 42, seen in the 40-ft.910 On 4 February, Herschel used the 10-ft for the nebula and its companion (M 43). Also M 77 was seen on that night. However, the main session started in September. M 5 was seen with the 7-ft, M 73 with the 10-ft, M 75 with the 20-ft and M 72 with the 40-ft. However, most observations were made with Herschel's new favourite, the X-foot: M 2, M 3, M 11, M 15, M 22, M 26, M 28, M 30, M 33, M 72, M 74, M 81 and M 82 (see Table 5-23). He also pointed the telescope at NGC 7009 (IV 1) in Aquarius ("my planetary"). On 25 May, he made his final observation of Uranus (the 40-ft was used). From 13 July the Herschel family spent their summer vacation in Scotland, staying there for three months.

On 19 January 1811, Herschel observed the Andromeda Nebula with the X-foot: "there is no sign of resolvability, on the contrary the nebulosity seems to be more milky". Later that night, the X-foot and 40-ft were pointed to his favourite object: the Orion Nebula. On 13, 15 and 16 March, it was seen for the last time, completing 38 years of observing.911 Starting on 1 March 1774, telescopes with apertures from 4.5 to 48 inches were used to reveal the secrets of the great nebulous mass. In total, four sketches were made of M 42, dating 4 March 1774, 11 November 1776, 25 January 1778 and 13

March 1811 (Figure 3-30). They also show the central ‘Trapezium’, treated as a ‘multiple star’ (θ Ori) and listed in the first catalogue of double stars as III 1.

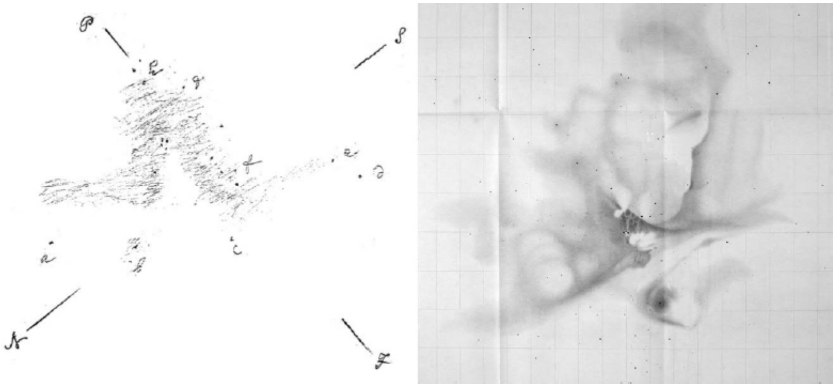


Figure 3-30: Famous images of the Orion Nebula. Left: William’s last sketch, made on 13 March 1811 with the 7-ft. Right: John’s elaborate drawing, made in 1837 at the Cape at the 20-ft reflector; Herschel J. (1847: Plate VIII).

But there was much more to see in Orion’s sword. The northern appendix, M 43, was often observed. In the vicinity, Herschel discovered V 30 (NGC 1977) around 42 Ori, called a ‘nebulous star’ V 31 (NGC 1980), the ι Orionis Nebula (only a part of M 42) and the obscure object III 1. Finally, NGC 1981, an open cluster north of NGC 1977, was found on 23 October 1780, though not catalogued. The object is not connected with the nebulae. Table 3-14 lists all 43 observations of the various objects in the M 42 complex.

Date	Telescope	Objects	Remarks
1 Mar. 1774	5.5-ft	M 42	
4 Mar. 1774	5.5-ft	M 42	1st sketch; Figure 1-2
9 Apr. 1774	5.5-ft	M 42	
11 Nov. 1776	10-ft	M 42, θ Ori	2nd sketch; Figure 1-11
18 Dec. 1777	10-ft	M 42	
25 Jan. 1778	10-ft	M 42, θ Ori	3rd sketch; Figure 1-11
26 Jan. 1778	10-ft	M 42, θ Ori	
7 Feb. 1778	10-ft	M 42, θ Ori	
25 Feb. 1778	10-ft	M 42, θ Ori	
15 Dec. 1778	10-ft	M 42, θ Ori	
7 Oct. 1779	10-ft	M 42, θ Ori	
5 Dec. 1779	10-ft	M 42, θ Ori	
22 Jan. 1780	10-ft	M 42, θ Ori	
19 Feb. 1780	10-ft	M 42, θ Ori	
26 Feb. 1780	10-ft	M 42, θ Ori	
10 Oct. 1780	10-ft	M 42, θ Ori	
22 Oct. 1780	10-ft	M 42, θ Ori	
24 Nov. 1780	10-ft	M 42, θ Ori	
21 Feb. 1781	7-ft	M 42	
1 Jan. 1783	small 20-ft	M 42	
31 Jan. 1783	7-ft	M 42	
20 Sep. 1783	small 20-ft	M 42, M 43, NGC 1980 (V 31)	
28 Sep. 1783	7-ft	M 42	
29 Sep. 1783	7-ft/small 20-ft	M 42	
7 Oct. 1783	7-ft	M 42	
3 Nov. 1783	20-ft	M 42, M 43, NGC 1980 (V 31), III 1	sweep 15
Date	**Telescope**	**Objects**	**Remarks**
16 Oct. 1784	20-ft	M 42, M 43, III 1	sweep 296
20 Dec. 1784	20-ft	M 42	
13 Feb. 1785	10-ft	M 42	
5 Oct. 1785	20-ft	M 42	sweep 458
18 Jan. 1786	20-ft	M 42, M 43, NGC 1977 (V 30)	sweep 510
31 Jan. 1786	20-ft	NGC 1980 (V 31)	sweep 517
23 Feb. 1786	20-ft	M 42, III 1	sweep 528
28 Nov. 1786	20-ft	M 42, NGC 1977 (V 30)	sweep 640, front-view
19 Feb. 1787	40-ft	M 42	front-view
30 Dec. 1799	10-ft	M 43	
14 Jan. 1801	X-foot	M 42, M 43	
12 Jan. 1803	10-ft	M 42	
11 Feb. 1806	X-foot	M 42	
30 Dec. 1806	10-ft	M 43	
4 Feb. 1810	10-ft	M 42, M 43	
31 Dec. 1810	10-ft	M 42, NGC 1980 (V 31)	
19 Jan. 1811	40-ft/X-ft/7-ft	M 42, NGC 1980 (V 31), III 1	
13 Mar. 1811	7-ft	M 42	4th sketch; Figure 3-30
15 Mar. 1811	7-ft	M 42	
16 Mar. 1811	10-ft	M 42	

Table 3-14: All 43 observations of M 42, the surrounding nebulae

and the Trapezium.[912]

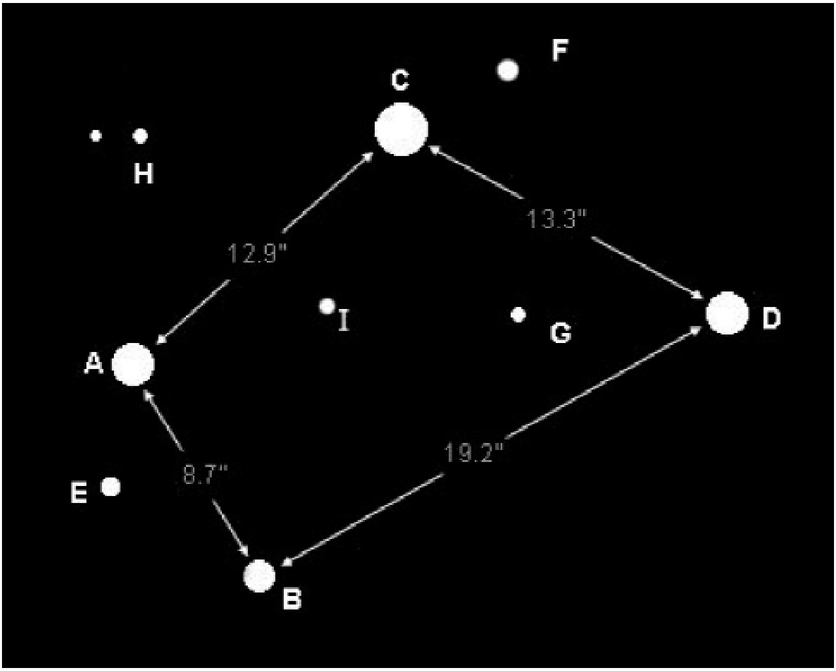


Figure 3-31: The Trapezium in the Orion Nebula; the four brightest members make up William's 'multiple star' θ Ori. The 6th star (F) was found by John on 13 February 1830.[913]

In September 1811, Herschel toured Scotland and northern England – a good opportunity for Caroline to observe from the cottage roof at Slough. The target was the Great Comet of 1811, already found on 25 March by a French astronomer. On 1 October, she wrote: "I swept for the Comet of which I received a notice this morning by a letter from Mr. Pigott (at Bath) to my brother, the observation being doubtful to a degree or two, and no account of what appearance it made. I swept for it in vain." Caroline was successful on the 4th: "I saw it for the first time in the place where I had matched it in Flamsteeds Atlas by a 2nd observation of Mr. Pigott's. Moon and twilight mad it appear but faintly." She located the comet in eastern Leo Minor, the brightness was 1.6 mag. On 8 September we read: "My brother Dietrich saw it in the night glass, which just took in the whole, but I did not extend beyond the field."[914] A sketch was made at the large sweeper (see Figure 3-29). The next day, Caroline

had some guests, “Ld. & Lady Harcourt came in the evening with Col. & Mrs. Harcourt and saw the Comet through my sweeper.”[915]

Meanwhile, William had observed the Great Comet from Scotland, writing on 2 September: “A new observatory near Glasgow where I had erected a 14 feet Newtonian telescope; the diameter of the large mirror 14 inches; about13¾ polished surface. I observed the Comet with this instrument, power about 110.”[916] On the 9th, he observed at Alnwick: “I viewed the Comet with a very good achromatic refractor, belonging to Earl Percy, which he had left with Mr. Smith for me to examine. Power about 65 or 70. The air was very clear and the Moon not being up I saw the head of the Comet in great perfection.”

When Herschel was back in Slough on 18 October, he had an illustrious guest, “his Royal Highness the Duke of Cambridge saw the Comet through the 10 feet telescope”. On the 19th, William and his brother Dietrich observed the comet with various magnifications. The latter left an interesting note, written in German, in *Review No. 8* (Figure 3-3). The period of the Great Comet of 1811 also saw the last use of the X-foot, on 15 November. The exceptional object was observed until 2 January 1812. The year 1811 brought observations on 35 nights for William and on 10 nights for Caroline.

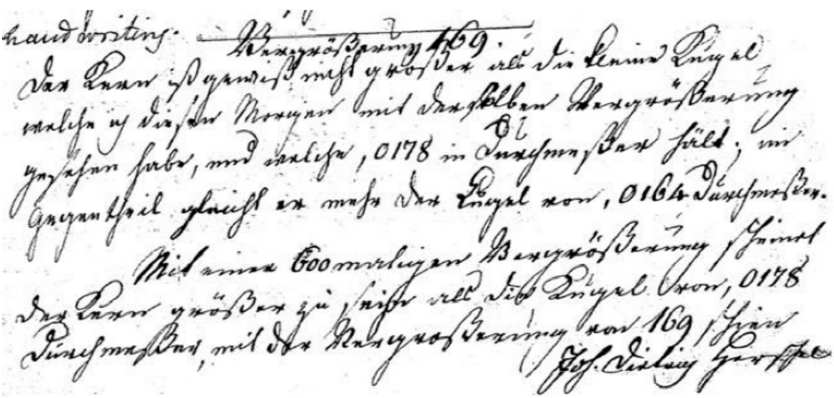


Figure 3-32: Dietrich’s note of 19 October 1811 about the Great Comet is written in old German ‘Sütterlin script’.[917]

Dietrich’s observation is an opportunity to collect the documented

observations, made by William's brothers over the years (Table 3-15). Perhaps there are more, but there is no note in the records.

Brother	Date	Object	Instrument	Remarks
Alexander	20 Jan. 1782	ζ Cnc	7-ft	double star I 24
Jacob	8. Aug. 1787	IV 51	20-ft	planetary nebula NGC 6818 (Sgr)
Jacob	19 Sep. 1787	Uranus	20-ft	
Alexander	17 Sep. 1789	Saturn	40-ft	Mimas seen
Dietrich	9 Jul. 1806	Saturn	10-ft	
Dietrich	8 Sep. 1811	Comet 1811	night glass	
Dietrich	19 Oct. 1811	Comet 1811	10-ft	German description
Dietrich	July 1813	Milky Way	naked eye	

Table 3-15: Documented observations of William's brothers. All observations were made in Slough, except the first (Bath).

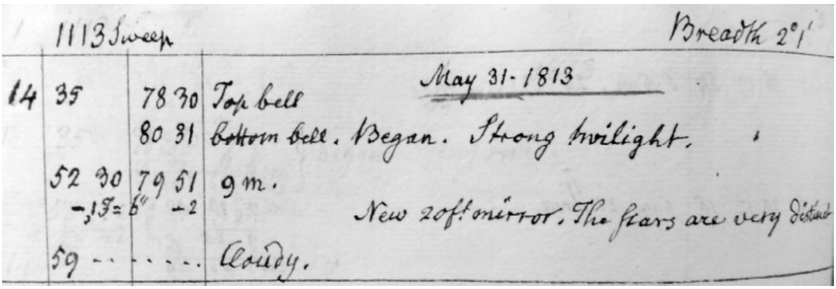
3.5.2. The last decade: William's death and Caroline's return to Hanover

On 1 January 1812, another comet appeared over Slough, discovered by Pons on 16 November 1811. William located the object with the 7-ft about 7° south of the Hyades, and estimated that it was of magnitude 7.2. Caroline saw the comet on the 15th, using the large sweeper and the 'double eye glass': "After a succession of cloudy weather it became necessary to sweep for the last obscure comet, and this evening to be fine, clear & frosty I swept all that of the heavens which my brother had pointed out to me before he left home this morning for town." After two hours, she eventually found the 'obscure comet' and made a sketch. William followed it until 21 January.

In September, Caroline looked in vain for another comet: "The newspapers mentioned at different times a telescopic comet but in such a manner that hardly the part of the heavens where one that to look for it could be guessed at." On her search with the large sweeper, she encountered M 51 on the 5th. In September and November, William tried to see Vesta with the 10-ft, but was not sure about it. In total, the year 1812 brought observations on 11 nights for William and on two nights for Caroline.

It will not be widely known that William performed a last sweep in 1813, more than 10 years after the campaign. Numbered 1113, it

was made on 31 May in Boötes, 15° southeast of Arcturus. Starting at 10:20 pm in 'strong twilight' the sweep ended 25 minutes later due to clouds (Figure 3-33).[918] It covered an area of 6° × 2°. Only a 9th mag star was seen, though three IC galaxies were in the area. With 13.5 mag they were well within the range of the 20-ft, which had just been equipped with a new mirror ("the stars are very distinct"). Although there is no hint, it is possible that William introduced the instrument to John, who was 21 at that time. Actually, a few years later, his son took over and continued sweeping at Slough with a modified 20-ft reflector, completed in 1820.


1113 Sweep — Breadth 2°1'

May 31. 1813

14	35	78 30	Top bell
		80 31	Bottom bell. Began. Strong twilight.
	52 30	79 51	9 m.
	−,15 = 6"	−2	New 20f. mirror. The stars are very distinct
	59 ..	....	Cloudy.

Figure 3-33: Record of sweep 1113, made with the 20-ft on 31 May 1813 in Boötes.

In July, William studied the Milky Way with the naked eye, describing "patches of easily resolved nebulosity" and divisions. In August, he made "Experiments on the distance of the stars" to get a relationship between apparent magnitude and distance. His younger brother Dietrich was present at the time.

After a year without any Messier object, seven were observed by William in 1813, and two by Caroline. She saw M 31 and M 3 on 5 and 18 September, respectively. On the 20th, William wrote: "There was a good deal of haziness which was perhaps the cause of my not seeing 40th & 97th of the Connoiss." December brought further views. On the 15th, the targets were Venus and Mars. M 31 and M 32 were finally seen on 26 December: "Great and small Nebulae in Andr. 20 feet in the meridian." William noted for M 31: "There is not the least appearance of its consisting of stars." This also was his last observation with the famous 20-ft reflector, which led him all through the sweep campaign. The year 1813 brought observations

on 18 nights for William and five for Caroline.

In February 1814, William observed Vesta, which was now called a ‘Planetule’. August 1814 brought the final use of the 40-ft (Figure 3-34). The target was Saturn, seen for the last time. Unfortunately, the 48-inch mirror was “extremely tarnished”. In the year 1814, William observed on only four nights; there were none for Caroline.

Although a strong wind hit Slough on 28 March 1815, the situation was still good enough for a spontaneous experiment:919 “In a violent hurricane I looked with a high magnifying power at a card 1000 feet off and could read the smallest letters distinctly, 7 feet reflector. The wind blew so violently that it was almost impossible not to be blown down when exposed to it.”

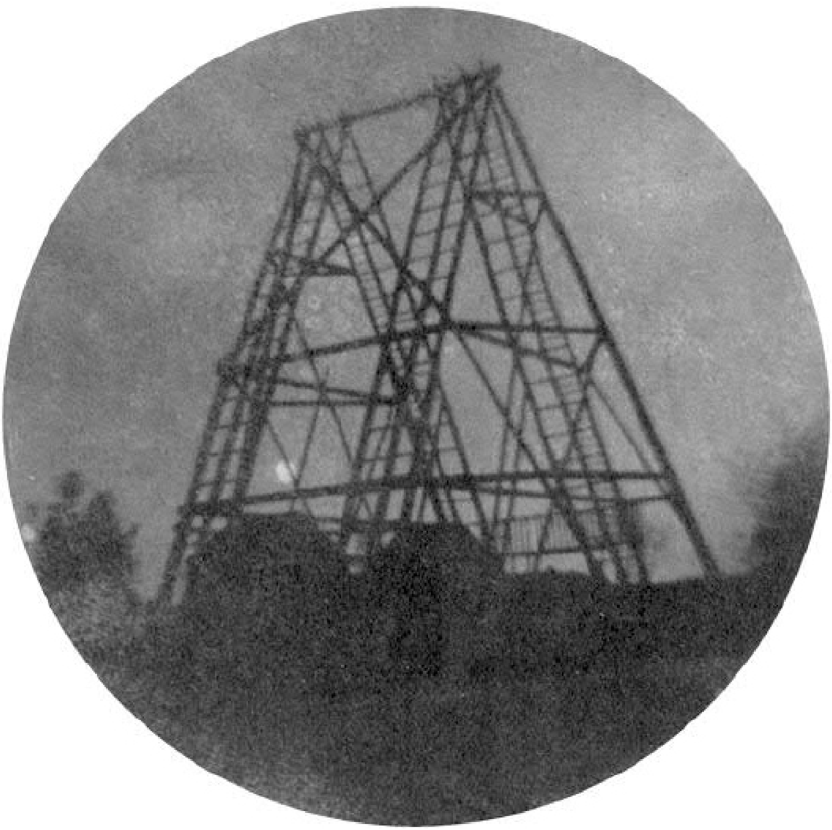


Figure 3-34: In 1839, when John returned from the Cape, he

photographed the decaying 40-ft telescope in the garden at Slough. It was eventually dismantled in December. A small ceremony was held. The Herschel family assembled within the tube and sang a requiem composed by John.

The next night, William and Caroline spent together to view a new comet: "The papers mention a comet discovered by Dr. Olbers; its motion was said to be towards the constellation of Perseus. The air being clear, I wished my Sister would sweep for it. She found it [with the large sweeper] within a degree or two following 41 Persei. I examined it with a 7 feet telescope; as it is in a very rich part of the heavens its nebulous appearance was mixed with small stars. Cloudy interruptions came on." Caroline wrote about the event: "This morning when I was at my Brother's, assisting him in his Library, he told me of a Comet being announced in the Morning Post discoveries at Bremen by Dr. Olbers which was moving towards Perseus. My Brother desired me to sweep for it. I began my search as soon as it was dark enough and by half past 8 o'clock I took the following eye-draft to my Brothers." Comet Olbers was in Perseus, 35° above the western horizon with a brightness of 7.2 mag. In 1815, William made only four observations, and Caroline one.

There were nearly the same numbers in 1816 (William 5; Caroline 0); target was the Sun. On 4 April, William received the Royal Hanoverian Guelphic Order. The collection of his titles was presented in the *Proceedings of the Royal Society*, giving an abstract of Herschel's 1817 paper in the *Philosophical Transactions*. The author is named: "Sir William Herschel, Knt. Guelp., LL.D., F.R.S."[920] In the spring of 1818 Herschel was awarded the Coat of Arms.

In autumn 1816, Caroline wrote:[921] "I took the opportunity of working on my MS. Catalogue at those times I was left without employment." What is meant by the 'catalogue manuscript'? There is no such item, made after the sweep campaign up to 1816. The only possibility is the *Zone Catalogue*. This is supported by a remark in the 'Memoir':[922] "This Catalogue was not completed until after her return to Hanover". However, there is a conflict with a statement, made by Caroline in a letter to John, written in Hanover

on 11 August 1823:[923] “I might make you a more correct catalogue of the 2,500 nebulae, which is not even begun, but hope to be able to make it my next winter’s amusement”. The *Zone Catalogue* was finished in March 1825 (see section 6.1). The folder contains a memorandum, written by her in 1819 at Slough: “The latter [General catalogue] is not what it ought to be, and if I can find time I wish to deliver one calculated for Jan. 0, 1800. May 1st 1819. C.H.” The subject is confusing.

On 10 October 1816, John wrote:[924] “I’m going, under my father’s directions, to take up a series of his observations where he has left them and continuing his scrutiny of the heavens with powerful telescopes.”

On 16 April 1817, we find an observation of the Double Cluster in Perseus (NGC 869/84) with the 10-ft, 37 years after William’s first view of it. Caroline was active in August and September: “During the time I was at my Brother’s House when he was on an excursion with his Family, I swept for new objects Aug. 15, 17 and Sept. 3, 4, 6 & 7, but saw nothing remarkable on those nights. Clouds and moonlight evenings prevented my profiting more by the time I spent at the observatory I had my several sweeps; of the Connoiss. the following numbers viz. 3, 5, 12, 81 & 82.” Finally, William viewed M 15 in Pegasus on 29 October with the 10-ft, 35 years after his first observation of the globular cluster with the 7-ft. It was his last non-stellar object. In total, 1817 brought observations on seven nights for William and six for Caroline. There was only one observation in 1818: William inspected the Sun on 24 July. On 15 November, he celebrated his 80th birthday (Figure 3-35).

1819 brought five observations for William and one for Caroline. On 4 July, she was informed about the Great Comet of 1819 (Figure 3-36).[925] The siblings observed it until 7 July, as it moved through Auriga and Lynx, being a 1st magnitude object. The comet had been discovered by Tralles on 26 June.[926] Caroline saw the it again on the 22nd: “27 Lyncis was lost in the light of the Comet. This Comet was visible to the naked eye July 3 and seen by many persons on that evening.” It is not known, whether William was present. If not, the observation on 7 July 1819 was the last that he made during his life. Caroline closed the *Review No. 8*.

Figure 3-35: William Herschel at the age of 81, wearing the Royal Hanoverian Guelphic Order, received on 4 April 1816.[927]

On 24 April 1820, Herschel agreed to be the titular first President of the newly founded *Astronomical Society of London* – he never actually took the Chair at a meeting.[928]

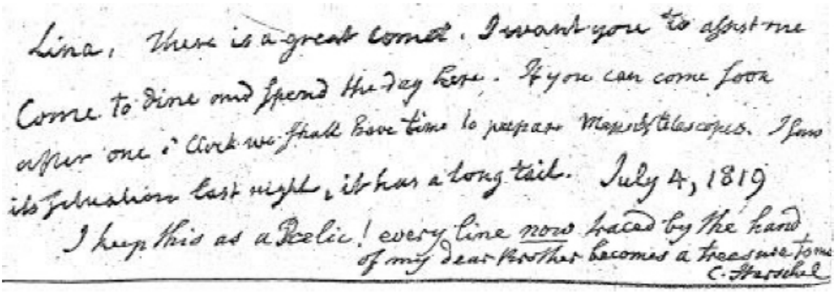

Lina, There is a great comet. I want you to assist me. Come to dine and spend the day here. If you can come soon after one o'clock we shall have time to prepare Maps & telescopes. I saw its situation last night, it has a long tail. July 4, 1819
I keep this as a Relic! every line now traced by the hand of my dear Brother becomes a treasure to me. C. Herschel

Figure 3-36: William informed his sister about the Great Comet of 1818; note Caroline's remark after the date.

The star reviews, finished on 26 September 1783, yielded many double/multiple stars, catalogued in the first and second catalogues of double stars.[929] Later, 145 further objects were found, designated N1–145 by Caroline; 105 of them were seen in the sweeps with 20-ft. The remaining 40 are due to the 'Review of the Ecliptic'.[930] This mission, designed to find asteroids, lasted from 4 September 1801 to 3 January 1802. First the 7-ft (460 ×) was used, then the 10-ft (600 ×). N1 in Virgo was discovered on 24 January 1784 (sweep 125) and N145 in Ursa Major on 30 September 1802 (sweep 1112). In late 1820, Herschel decided to publish the data with positions for 1800. The manuscript of his third catalogue is dated 1 February 1821.

The minimum separation is about 1". This is the double star N56 = 41 Aqr, found in sweep 609 (13 October 1786). The components have 5.4 and 6.7 mag. They were resolved with the 18.7-inch reflector. It is astonishing that even closer pairs were seen with the 6.2-inch. The reason: the star reviews, exclusively done for searching double stars, offered much more time and power (227 ×, 460 ×) for each object than observing in the sweeping mode with 157 ×. Close pairs could be overlooked when encountered in the moving field of view. The widest pair is N12 = 87 Ari (Bode), found in sweep 264; the stars of 5.8 and 9.4 mag are 170" apart.

Two double stars appear twice in the catalogue: N6 = N40, N128 = N133. The former case is the famous triple in the centre of the Trifid Nebula M 20, seen in sweeps 236 and 566. The latter is also identical to I 50 (Aqr). Nine other objects are already listed in the

former double star catalogues. Herschel's final paper 'On the places of 145 new Double Stars' appeared 1822 in the first volume of the *Memoirs of the Astronomical Society of London*.[931] For the title page and the first two entries see Figure 3-37. The most prominent entry is Deneb, seen in sweep 959 (11 September 1790): "It has a very small star directly following about 1' distant." Caroline catalogued the pair as N73.[932] She later was happy that John continued the work of his father on double stars:[933]

His [William's] observations on double stars were from the first to the last the most interesting subject; he never lost sight of it in his papers on the construction of the heavens, &c. And I cannot help lamenting that he could not take to his grave with him the satisfaction I feel at present at seeing his *son* doing him so ample justice by endeavouring to perfect what he could only begin.

XV. *On the places of* 145 *new Double Stars.* *By Sir* WILLIAM HERSCHEL, *President of this Society.*

Read June 8, 1821.

(1.) 125 Sweep, Jan. 24, 1784. A very pretty treble star, making an equilateral triangle, all equal and w. 3d class far, or 4th near. 93 (τ) *Virginis* f. . . . n. 0° 5′, R. A. 14^h 4′ ±″, P. D. 87° 24′.

(2.) 162 Sw. March 11, 1784. A double star preceding the head of *Monoceros*, not in Fl., a very considerable star. 15 *Monocerotis* p. 10′ 30″, n. 1° 12′, R. A. 6^h 18′ 43″, P. D. 78° 43′.

682 Sw. Jan. 11, 1787. Double. 75 (1) *Orionis* f. 14′ 3″, n. 1° 24′, R. A. 6^h 19′ 22″, P. D. 78° 35′.

Figure 3-37: Herschel's last publication appeared in 1822, the third catalogue of double stars.

John Herschel continued the double star work in early 1821, together with James South. In 1867, he compiled a *Synopsis of all Sir William Herschel's Measures of Double Stars*; the work covers 115 pages in volume 35 of the *Memoirs of the Royal Astronomical Society*.[934] It also contains additional remarks and cross-identifications to other double star catalogues, like the famous one

of Wilhelm Struve (the stars are designated Σ).

William Herschel died on 25 August 1822 in Slough. He was buried in the nearby Church of St. Lawrence, Upton; the epitaph is shown in Figure 3-38.[935] A stained glass window was recently installed, showing the great astronomer at the 40-ft front-view reflector.

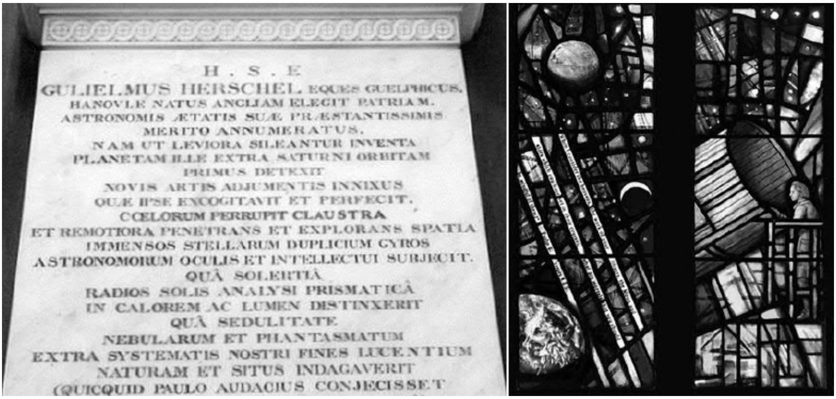


Figure 3-38: Herschel's epitaph and a modern glass window in the Church of St. Lawrence (Upton), showing the 40-ft.

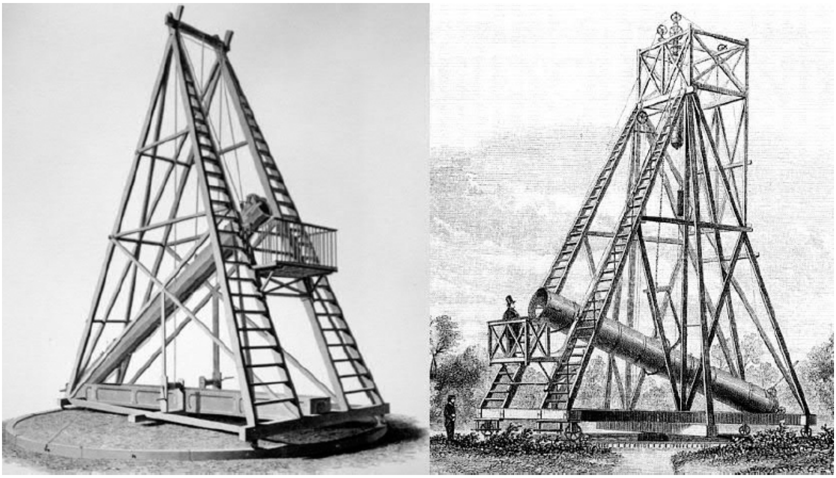


Figure 3-39: Left: 15-inch front-view reflector with 25 feet focal length, built by John Ramage in 1820 and used at Greenwich; right: Lord Rosse's 36-inch Newtonian with 27 feet focal length, erected at Birr Castle in 1839.

Herschel's influence on observational and theoretical astronomy remained. This also applies to the construction of telescopes, as can be seen in the large reflectors of Lord Rosse and John Ramage (Figure 3-39).[936]

Although William Herschel had written a fragmentary *Memorandum* about his life, we owe most of the information about him and his family to three important women. The first, of course, is Caroline with her two *Autobiographies*. The second is Mary Cornwallis Herschel ('Mrs. John Herschel'), who published the *Memoir and Correspondence of Caroline Herschel* in 1876. Finally, we have Constance Anne Lubbock's book of 1933, titled *The Herschel Chronicle* (see Introduction).[937]

On 28 October, only two months after William's death, Caroline hastily returned to Hanover, after living 50 years in England, starting as a unexperienced singer and ending as a well-respected astronomer. She found a home in Dietrich's house in the Marktststraße, living there till the death of her younger brother on 18 January 1827.[938]

Caroline brought her small sweeper and a 7-ft reflector to Hanover. On 11 August 1822, she wrote to John about the latter: "I am amusing myself with having the seven-foot mounted by Hohenbaum, though I have not even a prospect of a window for a whole constellation, but it shall stand in my room and be my monument as the forty-foot is yours."[939] Indeed, the situation at Dietrich's house was not favourable for observing: "the heavens is no getting, for the high roofs of the opposite houses."[940] Caroline mainly viewed with the naked eye – and had the pleasure watching Comet Halley in 1836; on 31 January she made a naked-eye drawing (Figure 3-40). Her beloved small sweeper became the chief ornament of her sitting room.

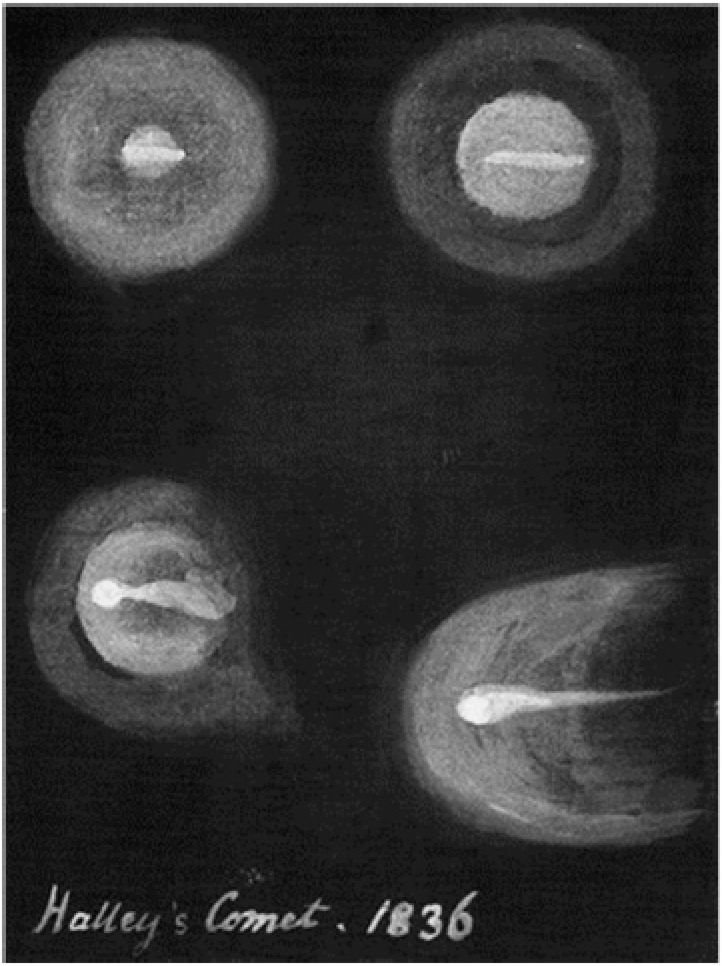


Figure 3-40: Caroline's fine drawings of Comet Halley, observed with the naked eye in 1836 from her home in Hanover. The bright appearance was intensively studied by John from Feldhausen.

Caroline was critical about her status in the shadow of William:941 "I did nothing for my brother, but what a well-trained puppy-dog would have done: that is to say, I did what he commanded me. I was a mere tool which he had the trouble of sharpening." And further: "An observer at your twenty-foot when sweeping, wants nothing but a being who can and will execute his commands with the quickness of lightning; for you will have seen that in many sweeps six or twice six objects have been secured and described in

one minute of time."

Caroline's last years in Hanover were pretty quiet. In 1846, she received another honour (after the RAS *Gold Medal*), the *Gold Medal for Science* from Friedrich Wilhelm IV. It was sent by Alexander v. Humboldt: "In recognition of the valuable service rendered to Astronomy by you as the fellow-worker of your immortal brother, Sir William Herschel."[942] Caroline died on 9 January 1848 at the age of 97 (Figure 3-41).

Figure 3-41: Caroline at the age of 97, shortly before her death in 1848. She points to a figure of the planetary system.

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804 Herschel W. (1796a, 1796b, 1797, 1799).

805 Pickering (1884a, 1899) has analysed Herschel's catalogues on stellar brightness – and was fascinated. They influenced all modern works on stellar magnitudes. Holden wrote: "No research of Herschel's was more laborious than the elaborate classification of the stars according to their comparative brightness, which he executed during the years 1796 to 1799. It was directly in the line of his main work to find out the construction of the heavens." Holden (1881:130).

806 Sullivan (2017).

807 The German astronomer Johann Encke (1791–1865), working at Berlin Observatory, is also the discoverer of the narrow 'Encke division' of the Saturn rings.

808 NGC 3342 (III 5) was discovered on 18 January 1784 in sweep 83: "The faintest and smallest Nebula imaginable. I viewed it a long while and with a higher power than the sweeper."

809 NGC 3342 (III 5) is in the *Zone Catalogue*, but not NGC 3332 (I 272).

810 Herschel W. (1797: 293).

811 RAS C.4/3: 18.

812 Herschel C. (1798). The copy presented to William is archived as RAS C.2/8.

813 The 'Index' is the essential tool to locate the observational data (like the date) in Vol. 2 of Flamsteed's *Historia Coelestis* for every star in the *British Catalogue*, which is in Vol. 3.

814 Bennett (1976a). Charles IV (1748–1819), King of Spain.

815 RAS W.2/1.13: 21.

816 From a watercolour illustration of c. 1800.

817 Paz et al. (2004); Ring (2010).

818 Herschel W. (1797).

819 The identity of 'Lord Storker' is unknown.

820 Stephen Lee (1770–1835) was Clerk and Librarian to the *Royal Society*. However, there was a third independent discoverer, the French astronomer Alexis Bouvard (1767–1843).

821 Hughes (1999); Olson, Pasachoff (2012); Sullivan (2017). The comets, seen by the Herschel's are listed in RAS C.4/3: 4.

822 Carolyn Shoemaker (*1929) used photography to search for comets, thus, Caroline is still the 'visual' recordholder. William's sister, however, was not the first women to discover a comet. The honour goes to Margaretha Kirch (1670–1720), the wife of the German astronomer Gottfried Kirch; on 21 April 1702 she found the bright comet of that year.

823 Hoskin (2013 :129).

824 As already discussed, there are about 3500 non-stellar objects in the reach of Herschel's 20-ft (see section 5.1.2). However, this would not only mean to sweep the 10% remaining sky regions. Even more important are the gaps in each sweep. To fill them would mean a whole new mission. Due to Herschel's sweep method, this is an impossible task.

825 N118 was supposed to play a role in the drama of sweep 1096.

826 In 1971, Halton Arp claimed that NGC 4319 and Mrk 205 are a physical pair; this would ruin the standard theory of a cosmological redshift. On 30 April 1786 (sweep 558), Herschel observed pretty near the brightest quasar, 3C 273 in Virgo, shining at 12.5 mag; see Steinicke (2016b). He saw the galaxy NGC 4420 (II 23), only 42' northwest.

827 Dreyer (1895, 1908).

828 Frank Bellamy (1863–1936), British astronomer, working at Radcliffe Observatory, Oxford. Guillaume Bigourdan (1851–1932), French astronomer, working at Paris Observatory; he discovered 70 NGC- and 253 IC objects.

829 RAS W.5/12.3: 448.

830 RAS W.2/1.13: 31.

831 The other case, though less spectacular, is NGC 1750 (VIII 43) and NGC 1758 (VII 21), found on 26 December 1785 (sweep 493) in Taurus. The centres of the open clusters are only 13' apart. Owing to their different distances they are not physically connected.

832 Herschel W. (1799).

833 RAS W.2/1.13: 36.

834 Winterburn (2017: chapter 15). Sophia Maskelyne (1752–1821) married Nevil in 1784.

835 Note that the much larger 25-ft reflector (‘Spanish telescope’) had the same aperture. However, its focal ratio was 1:12.5. Due to the same mirror diameter of 24 inches, both instruments may be confused.

836 William Watson Jr made a drawing (see title page of this section); RAS W.5/5.

837 Herschel’s X-foot is the prototype of the modern Dobsonian reflector. It typically also comes with a focal ratio of 1:5.

838 RAS W.2/2.5: 53.

839 Dreyer (1912a: lv). Samuel Vince (1749–1821), Plumian Professor for Astronomy at Cambridge.

840 ‘Miss Wilson’ is the sister of Patrick Wilson. ‘Miss Baldwin’ is Sophia Baldwin (1783–1820), daughter of Mary Herschel’s brother Thomas.

841 This is the last entry in a *Journal*; RAS W.2/1.13.

842 Herschel Mrs. J. (1876: 98).

843 In sweep 463 on 9 October 1785, it seems that Herschel reversed the AR order: GN 1163 was seen earlier than GN 1164, but the latter got the lower AR. But this is due to the different offsets in the field of view. This concerns the galaxies NGC 1087/90 (II 466/65) in Cetus, having 10.9 and 11.8 mag.

844 Herschel W. (1800a).

845 Herschel’s symbols are used here; for a modern treatment see Steinicke (2019c); see also King (1979: 136).

846 In extreme cases (young, trained observer), the entrance pupil can

reach a = 0.3 inches (8 mm). Some amateurs use oxygen or even drugs to dilate it for more light.
847 Clerke (1895: 101).
848 Warner (1979).
849 Herschel also gives values for his finders (refractors). For that used at the 7-ft with A = 0.75 inches (single eye lens), he gets P = 3.6; for the achromatic finder at the 20-ft with A = 1.17 inches, he gets 4.5 (transmission was set to 1).
850 Herschel W. (1800b, c, d); see also Lovell (1968), Ring (2000).
851 Lubbock (1933: 298).
852 Herschel Mrs. J. (1876: 268).
853 II 905 is erroneously called "III 905".
854 See section 6.3 and Steinicke (2010a: chapter 6.19).
855 Steinicke (2010a: chapter 8.6). Heinrich d'Arrest (1822–1875), Danish astronomer and Director of Copenhagen Observatory. He discovered 310 NGC objects.
856 Steinicke (2010a: chapter 9.22).
857 William Christie (1845–1922), British astronomer, working at Greenwich.
858 Christie (1911).
859 RS MS/278.
860 SAO refers to the *Smithsonian Astrophysical Observatory Star Catalogue*.
861 Actually, Herschel had seen this star already in sweep 1074 on 20 December 1797, correctly identified by Caroline.
862 Both were eventually seen in sweep 1111 on 26 September 1802. Curiously, a third nebula, about 1' preceding the two galaxies, was discovered in the same field; it is only a 14th mag star.
863 RAS W.4/31.
864 RAS W.3/1.12: 39.
865 It is unknown, why Bode did not chose 1800, later taken by the astronomers as the new standard equinox.
866 The two galaxies were independently found 1779 by the Johann Gottfried Koehler in Dresden.
867 RAS W.4/33.1.
868 Bode (1782).
869 Steinicke (2007a).
870 Until that date, marking the end of the sweeps, Caroline had observed M 81 and M 82 nine times with her sweepers.
871 The bubble (level) is the tool to check the telescope's horizonal adjustment.
872 Herschel J. (1847); Steinicke (2010a: chapter 5); Cozens (2008).
873 These Herschel objects do not appear in the *Slough Catalogue*, because they were not observed by John (Table 3-11).
874 This was William's last class IV object – before John created IV 79 = M

82.

875 The results were presented in Herschel W. (1803b, 1804).

876 RAS W.2/2.7: 4. The results of the transit observation were published in Herschel W. (1803a).

877 John observed higher declinations in 1831. On 4 October, he discovered the loose open cluster NGC 188 in Ursa Minor at 84° 09'. On 3 November he even reached 89° 47', finding the 14.1 mag galaxy NGC 3172, located only 5' from the northern pole (at that date); John named it Polarissima Borealis.

878 RAS W.3/1.12: 40. The name is due to Piazzi; Ceres is the Roman goddess of agriculture. However, Bode suggested the name Juno, later taken up for the third minor planet.

879 Wilhelm Olbers (1758–1840), German physician and astronomer, working in Bremen.

880 Herschel W. (1802a).

881 Cunningham (2017).

882 Only sweep 1109 was made in Lyra; Vega was seen without any comment.

883 'Lord Stanhope' is Charles Stanhope, 3rd Earl of Stanhope (1753–1816), a British statesman and scientist. 'Mr. Varley' is the English water-colour painter and instrument maker Cornelius Varley (1781–1873). That all four Galilean moons are invisible (being behind or in front of the planet), appears only a few times in a century.

884 Together with the former annual summaries, the sweep period 1783–1802 is covered. For other events see the Timeline.

885 RAS W.4/28.2.

886 RS L&P/12/34; see also Hoskin (2005c).

887 William, Mary and John visited Paris from 13 July to 15 August 1802. On 27 July, William met Messier and on 8 August he had an audience with Napoleon Bonaparte (1749–1827); the French mathematician Pierre-Simon de Laplace (1749–1827) was also present; see Lubbock (1933: 308–312).

888 Hoskin (2005c).

889 Herschel W. (1802b).

890 Herschel J. (1847: 128).

891 After Caroline finally assisted in sweep 1112 on 30 September 1802, there is no observation of her until 27 January 1807. She now lived in Upton, 10 minutes away from her 'observatory'. Until 13 March 1804, she revised the sweep records. In 1805, the 'Spanish telescope' must be packed for delivery, In August 1806, she compiled a list of all books and manuscripts in William's library (RAS W.7/11) and in autumn she helped in re-polishing the 40-ft mirror; Herschel Mrs. J. (1876: 110–112).

892 Thomas Jones (1756–1807) was Head Tutor at Trinity College, Cambridge.

893 The identity of 'General Richardson' is unknown. He is not mentioned in Caroline's visitor list (RAS C.3/1.1).

894 Herschel W. (1805b); the paper was read on 16 May 1805. A year later, another paper appeared, titled 'On the Quantity and Velocity of the Solar Motion'. The manuscript was read to the *Royal Society* on 27 February 1806; Herschel W. (1806). See footnote 172 and the analysis of Herschel's work on this subject in Hoskin (2012a).

895 Herschel W. (1805a).

896 The X-foot was given in 1814 to Lucien Bonaparte (1775–1840), younger brother of Napoleon; see Maurer (2011).

897 Views up to the zenith were the speciality of the 20-ft. However, there was an exceptional 40-ft observation near the zenith in the test sweep on 23 November 1788; see Table 2-56.

898 Lubbock (1933: 313).

899 RAS W.1/8.23.

900 Jean Louis Pons (1761–1831), French astronomer. The object is known as Biela's comet; in 1826 the German astronomer Wilhelm v. Biela (1782–1856) found that it is periodic. Alas, the cosmic object broke into pieces in 1852.

901 Joanna Baillie (1762–1851), Scottish poet and dramatist.

902 Prince Edward, Duke of Kent and Strathearn (1767–1820); Louis Phillipe II, Duke of Orléans (1773–1850).

903 George Griesbach, the son of Caroline's oldest sister Sophia Elisabeth (1733–1803), was a musician in the Queen's band.

904 RAS C.3/1.2: 59. 'Count Münster' is Ernst zu Münster (1766–1839), a German statesman in the service of the House of Hanover. The identity of 'General Cartwright' is unknown. 'Mrs. Beckedorff' is Charlotte Beckedorff (†1840), chambermaid and servant of Queen Charlotte. After the Queen's death in 1818, she moved to Hanover. Caroline first met her on 8 February 1802; later the women became friends.

905 Lubbock (1933: 322). The mentioned guests were: Prince Augustus Frederick (1773–1843), Prince Demetrius Augustine Gallitzin (1770–1840), Charles Lennox, 'Lord Darnley' (1764–1819), Count Georg Ludwig von Oeynhausen (1734–1811), Countess Leonor von Oeynhausen (1750–1839); 'Admiral Boston' is Frederick Paul Irby (1779–1844), son of the 2nd Baron Boston.

906 Shute Barrington, Bishop of Salisbury (1734–1826); 'Lord Lewsham' probably is George Legge, Viscount Lewisham (1755–1810). The identities of 'Lady F. Murry' and the '2 Lady's Strangways' are unknown.

907 RAS C.1/1.3: 104.

908 Herschel Mrs. J. (1876: 117). In her last 16 years, she had problems, but this was due to her age; Hoskin (2013: 207).

909 Prince Adolphus Frederick, 1. Duke of Cambridge (1774–1850).

910 The great reflector was also used for Uranus on 3 and 25 May.

911 Caroline never observed M 42 in her own sweeps. Of course, she saw the nebula in William's telescopes. It was only on 18 December 1783 that he came near to the place: "I swept with a power of 15 from the horizon as far as θ Orionis."
912 Most observations were described by Holden (1882: 26–36).
913 Dreyer (1912a: liii) later asked, why Herschel has not noticed the fifth and sixth star (E & F), which would be easily visible in the 40-ft; see also: Steinicke (2010a: chapter 9.6.10).
914 The 'night glass' (a binocular) was constructed by William. It probably had an aperture of 2.5 inches, a magnification of 5 to 8 and 4° 41' field of view; see Dreyer (1912b: 42, 504, 587). Caroline already got a 'night glass' in August 1799 after her return from Greenwich (it was a present from Maskelyne); see Lubbock (1933: 297). On 4 November, a 'new 10 feet', equipped with a 'double eye glass', was operational.
915 'Ld. & Lady Harcourt' are William Harcourt, 3rd Earl Harcourt (1743–1830) and his wife Mary.
916 The reflector was sold to Glasgow Observatory in 1811; it was transferred to the Royal Observatory at Cape Town in 1828; see Maurer (1996). Herschel built about 70 telescopes, which were sold to various persons and organizations worldwide. However, very little astronomical research was done with them; see Dreyer (1912a: li).
917 Translation by the author: "Magnification 169. The nucleus is certainly no larger than the little ball I saw this morning with this magnification and a diameter of 0.0178'; on the contrary, it is more like the ball of 0.0164' diameter. At magnification 600, the nucleus appears to be larger than the ball of 0.0178' diameter at magnification 169. Joh. Dietrich Herschel."
918 RS MS/278.
919 RAS W.2/2.8: 20.
920 The titles are: Sir, Knight of the Guelphic order, honorary doctor of law (LL.D.) and Fellow of the *Royal Society* (FRS). See the critical papers 'The Herschel Knighthoods: Fact and Fiction', Hanham, Hoskin (2014), and 'William Herschel's Application for the Coat of Arms', Hoskin (2016). See also the lists in RAS C.4/3: 29 and RAS W.7/9.
921 Herschel Mrs. J. (1876: 126).
922 Herschel Mrs. J. (1876: 145).
923 Herschel Mrs. J. (1876: 171).
924 Buttmann (1970: 20).
925 RAS W.1/8.43, Herschel Mrs. J. (1876: 131).
926 Johann Georg Tralles (1763–1822), German mathematician and physicist.
927 Portrait made by the English painter William Artaud (1763–1823) in the summer of 1819.
928 Since 1831 the *Royal Astronomical* Society (RAS); see Dreyer, Turner

(1923).

929 The last object, listed in the second catalogue is III 114 in Monoceros, found on 23 January 1784 in sweep 99.

930 15 stars were communicated to Wollaston in a manuscript (M.S.), to be included in his star catalogue of 1789.

931 The manuscript is in RAS W.2/5.4: first pages; it is followed by the observations of new double stars. The published catalogue is Herschel W. (1822).

932 Deneb (1.3 mag) and its 11.8 mag companion (1.3' east) are not a physical pair.

933 Letter to John, 4 June 1831; Herschel Mrs. J. (1876: 246).

934 Herschel J. (1867); see also: Dreyer (1912b: 661–698). James South (1785–1867), eminent British amateur astronomer.

935 The full text was published by Lynn (1881).

936 John Ramage (1788–1835), Scottish optician and telescope maker; King (1979: 199).

937 RAS W.7/8, Hoskin (2003a), Lubbock (1933). Herschel Mrs. J. (1876); only a year later, a German version of the Memoir appeared: Scheibe (1877), which was republished in 2013.

938 Alexander had moved to Hanover on 2 September 1816. Dying there 1821, Dietrich was her only surviving brother until 1827.

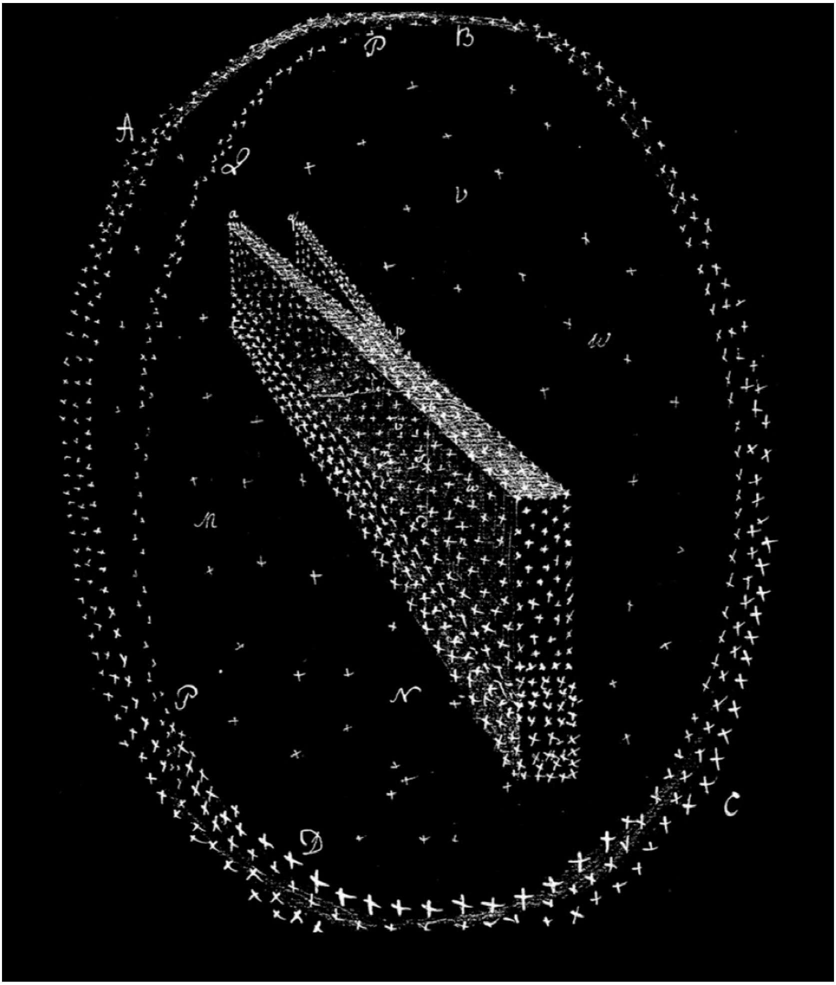
939 Herschel Mrs. J. (1876: 171). Obviously, she had taken only the optics to Hanover. Gottfried Hohenbaum (1785–1857), Hanoverian court mechanic.

940 Herschel Mrs. J. (1876: 161).

941 Herschel Mrs. J. (1876: 142, 144).

942 Lubbock (1933: 374). Alexander von Humboldt (1769–1859), German polymath, geographer, naturalist and explorer. Being a great admirer of William and John Herschel, he presents their work in detail in the third volume of this monumental book *Cosmos*. Friedrich Wilhelm IV (1795–1861), King of Prussia.

4. The stellar system and the nature of nebulae and star clusters



In this chapter, we first focus on Herschel’s ideas about the spatial arrangement of the stars, forming the stellar system. The major method to reveal the ‘construction of the heavens’ is the so-called ‘star gages’, performed in the sweeps.[943] He simply counted the number of stars seen in the eye-piece of the 20-ft telescope. First

results were published in the paper of 1784, which gives an idea about the distribution of stars in and off the Milky Way.

But Herschel was not only interested in the two-dimensional view. Basing his examination on the assumption of a uniform star distribution in space, he derived a relation between the number of stars in the field of view and their maximum distance. It led him to determine the boundary of the stellar system. Herschel thought it to be a finite, flattened ‘stratum of stars’. From the mass of star count data, he selected a subset along a great circle on the sphere. This yielded a graphical representation of a section of the Milky Way. Herschel’s figure, presented in the paper of 1785, became very popular – though it was sometimes misunderstood.

However, due to later observations, partly made with the 40-ft reflector, Herschel was forced to reject the assumption of a constant star density. He had found a large number of star clusters in the Milky Way. On the other hand, there were ‘vacant fields’, like the obscure ‘hole in Scorpius’, found in 1784. Thus, the stratum now appeared to him as an inhomogeneous mix of stars, clusters and voids. He concluded that the section does not show the true boundary of the ‘stratum’.

John Herschel continued the star counts in the southern hemisphere, inspecting a large number of fields. He became more and more critical about his father’s ideas, finding the stellar system much more complex, with the Sun located in a vacant region.

The second part of this chapter concerns Herschel’s detailed interpretation of the results of the sweeping campaign. It appeared in a series of four papers, named ‘Astronomical observations’, published between 1811 and 1818. The first two provided a general view of all nebulae and star clusters. A generalized classification should reveal their nature, physical relation and evolution. Sketches illustrated his ideas. Here Herschel also presented his obscure 52 regions of ‘extensive diffused nebulosity’. The subject of the last two papers is ‘profundity’, derived from his method of determining the spatial distance by ‘star gages’. He applied it to stars and star clusters.

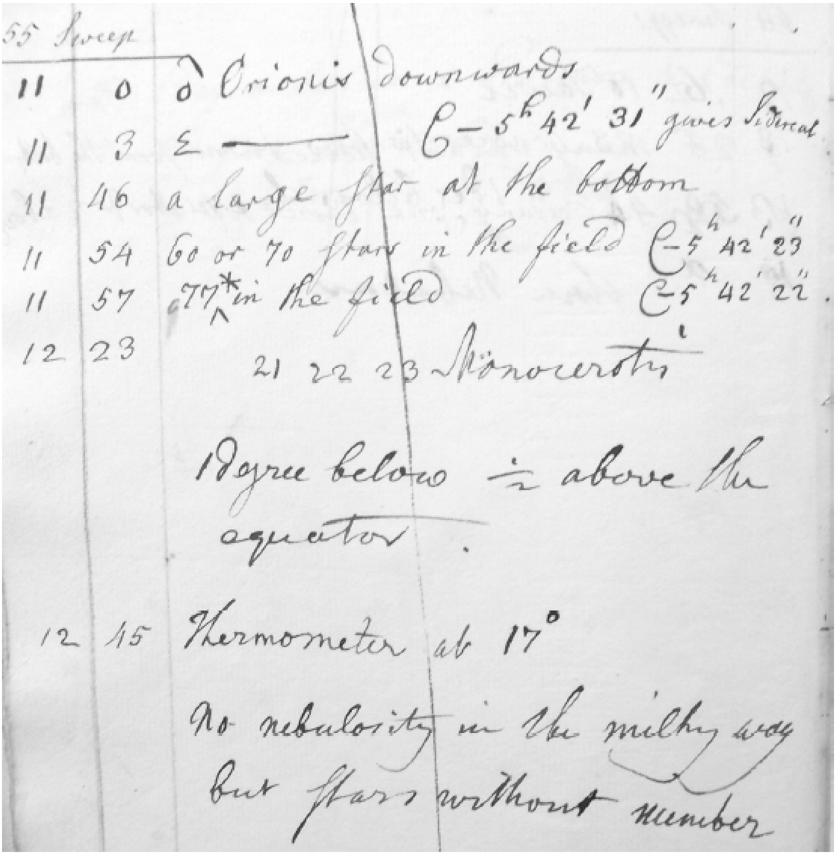
4.1. 'Star gages' and the structure of the Milky Way

4.1.1. The first paper on the 'Construction of the Heavens' (1784)

On 19 December 1783 at 11 pm, Herschel started sweep 55. The first object encountered in the field of view of the 20-ft was the bright star δ Ori. About 50 minutes later, the Milky Way in Monoceros appeared: "no nebulosity in the milky way but stars without number". He decided to count them, finding "60 to 70 stars in the field" (Figure 4-1). Three minutes later, another field was counted at the same PD, yielding 77 stars. This marked the beginning of the 'star gaging' campaign, lasting until 29 September 1802 (sweep 1111).[944] Not initially planned, it became an integral component of sweeping, although only a minor part of the time was spent on it.

In sweeps 80 and 81 (18 January 1784, Herschel again inspected parts of the Orion/Monoceros region, now finding a maximum number of 110 stars in a single field of view. From sweep 55 to 189 only 12 contain a gage, all performed in the Milky Way.

How was a single-field gage performed? At the celestial equator, stars cross the standard field (15') in a minute, entering at the eastern edge and leaving at the western. To count 50 or more stars, tracking by the 'side motion' was applied. Herschel followed them for about three minutes. After the count, the tube was pushed back to stop at the meridian position by an iron plate.



55 Sweep		
11	0	δ Orionis downwards
11	3	ε —— ζ – 5h 42′ 31″ gives Sidereal
11	46	a large star at the bottom
11	54	60 or 70 stars in the field ζ – 5h 42′ 23″
11	57	77 * in the field ζ – 5h 42′ 22″.
12	23	21 22 23 Monocerotis
		1 Degree below ½ above the aequator.
12	45	Thermometer at 17°
		No nebulosity in the milky way but stars without number

Figure 4-1: Herschel's first star gages were made in sweep 55 (at 11.54 pm and 11.57 pm).945

In sweep 185 (27 March 1784), William counted off the Milky Way, in Hercules. A single field showed just 24 stars. Boötes, visited in sweep 189 on 12 April 1784, brought many new nebulae, thus there was little time for 'gaging'. Only one field was counted, getting "5 or 6 stars". This led to a methodical change in sweep 190 (same night). He now counted four fields along the sweep path, yielding 12, 6, 8 and 12 stars. Caroline noted an average number of 9.5 stars for the four fields. William made three other counts, each using six fields; the mean values were 6, 6.5 and 12. The position assigned to a multi-field gage was derived from the mean AR of the field centres and the mean PD between top and bottom of the sweep. Later 10 or even 13 fields were sampled for a gage. Of course, the

result was the average over the whole sweep breadth (ranging 1.8° to 4.6°) and does not represent a star number in a specific direction. The statistical variation in multiple counts could be considerable (the highest number in a field could be 10 times the lowest).

Herschel's 'star gages' had an ambitious goal: to reveal the form, structure and extent of the stellar system, being the home of the Sun, stars, clusters and perhaps the nebulae. When 58 gages were taken at the end of April 1784, he believed to have enough material for a first presentation of the results. The paper, titled 'Account of some Observations tending to Investigate the Construction of the Heavens' was read to the *Royal Society* on 17 June and appeared in 1784 in volume 74 of the *Philosophical Transactions*.[946]

In it, Herschel explains the 'Gaging the Heavens, or the Star-Gage': "It consists in repeatedly taking the number of stars in ten fields of view of my reflector near each other, and by adding their sums, and cutting off one decimal on the right, a mean of the contents of the heavens, in all the parts which are thus gaged, is obtained." However, this method was by no means always applied. The number of fields actually varied from 1 to 13.

Herschel's subject was the Milky Way (also called the Via Lactea). He had known about its optical appearance since 1773 from Ferguson's Astronomy:[947] "There is a remarkable track round the heavens, called the *Milky Way*, from its peculiar whiteness, which is found, by means of the telescope, to be owing to a vast number of very small stars, that are situate in that part of the heavens. This track appears single in some parts, in others double."

Moreover, the Harris maps showed the full circle of the Milky Way band, but also a remarkable division, stretching from Cygnus to Scorpius. Undoubtedly, Herschel had already seen this branching (known as the Great Rift) with the naked eye. Moreover, his telescopes showed that the Milky Way is an accumulation of an immense number of faint stars, varying in density along the band.

The appearance of the Milky Way and its stellar content had led Herschel to the assumption that the Sun was located in a finite, flat, branching 'stratum of stars'. How this structure creates the observed divided ring of stars on the sphere is demonstrated by a drawing,

published in his paper (compare Figure 4-15).[948] However, the collected observational data were not yet sufficient to determine the details of the stellar system, especially its spatial extent. Despite this, Herschel discussed the effect on star counts, made from the interior position of the Sun.

For the paper, Herschel selected some gages to illustrate the influence of the Milky Way band on the counted star numbers. He chose two areas with gages, performed between 13 and 24 April 1784 (sweeps 191, 194, 195 and 206). Here 8–13 fields were averaged. Two tables with six gages each, but different PDs, were created (Figure 4-2). The table for PD 92° to 94° (below the celestial equator) shows gages made in Libra and Ophiuchus and that for PD 78° to 80° (above the celestial equator) those in Leo, Virgo and Boötes. The numbers in the former region, nearer to the Milky Way, are about three times higher than in the latter. Table 4-1 gives the data from Herschel's collections.

N. PD 92 to 94°	
R.	Gage.
15 10	9 . 4
15 22	10 . 6
15 47	10 . 6
16 8	12 . 1
16 25	13 . 6
16 37	18 . 6

N. PD 78 to 80°	
R.	Gage.
11 16	3 . 1
12 31	3 . 4
12 44	4 . 6
12 49	3 . 9
13 5	3 . 8
14 30	3 . 6

Figure 4-2: Herschel's gages used for the 1784 paper; left: regions near the Milky Way, right: regions off the Milky Way.

Sw	Day	Con	Gage	Fields	AR	PD	Lat (°)
206	24	Lib	9.4	12	15 08 45	93 05	41.5
206	24	Lib	10.6	12	15 21 00	93 05	39.2
206	24	Oph	10.6	12	15 46 30	93 05	34.4
206	24	Oph	12.1	12	16 08 11	93 09	30.0
206	24	Oph	13.6	12	16 24 11	93 09	26.8
206	24	Oph	18.6	12	16 35 48	93 15	24.3
191	13	Leo	3.1	8	11 16 52	81 38	62.3
194	15	Vir	3.4	11	12 30 40	79 03	72.1
191	13	Vir	4.6	13	12 46 51	81 40	69.4
194	15	Vir	3.9	13	12 48 19	79 04	71.9
194	15	Vir	3.8	12	13 01 19	79 04	71.2
195	15	Boo	3.6	13	14 30 08	80 38	57.0

Table 4-1: Data for Herschel's published table. The second column gives the day in April 1784; the last column lists the galactic latitude. The six gages, made in sweep 206, are closer to the Milky Way and thus show higher star numbers. The positions are for 1690 (some AR values deviate from the draft).

Herschel knew that both the distance to the boundary of the stratum and the 'space-penetrating power' of the telescope affected the counts (see section 3.3.1). However, his investigation was based on only 58 gages: "It would not be safe to enter into an application of these, and such other gages as I have already taken, till they are sufficiently continued and carried all over the heavens." Of course, more observational data were needed – and he was eager to get them.

4.1.2. The second paper on the 'Construction of the Heavens' (1785)

The star counts continued on 9 May 1784 with sweep 210, now mainly using 10 fields for a gage (Figure 4-3). However, on 16 June (sweep 228), Herschel observed a single field in the Scutum Star Cloud, counting no less than 358 stars (Figure 4-4). Five minutes later, he made another gage. Again, the field appeared enormously rich and he decided to count only half of it. This 'half gage' brought 94 stars, thus 188 for the total field were registered. From now on,

Herschel counted in crowded regions ½, ⅓ or even ¼ of a field.

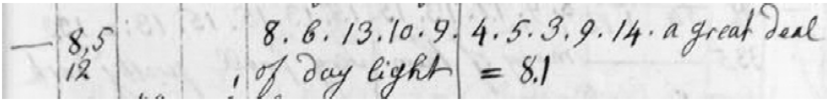

8,5 | 8. 6. 13. 10. 9. 4. 5. 3. 9. 14. a great deal
12 | of day light = 8.1

Figure 4-3: Sweep 210 with first 10-field gage; the average value is 8.1.[949]

The maximum was reached in sweep 254 (23 August 1784), made in the central summer Milky Way (Sagitta/Aquila border). The sky was "immensely rich", showing 147 stars in a quarter field, thus 588 in total. The same number appeared two minutes later at another place. Herschel noted: "All the time the whole breadth of the sweep equally rich with the last gage." As already done for the 1784 paper, he extrapolated the star number in this field (588) to a large rectangular sky area, now measuring 1^h in AR and 2° in PD. He not only estimated the total amount but also presented a calculation, considering the number of fields inside the area at the mean PD (73°) and the ratio of the circular field to the square area ($\pi/4 = 0.7854$). Herschel correctly got 343,636 stars.[950] He swept about 15 minutes in this crowded branch of the Milky Way. With respect to the breadth of 2° 26', he noted that "in all probability in this last quarter of an hour not less than 125,000 stars have passed my view".

Figure 4-4: Herschel's field (circle) in the dense Scutum Star Cloud, yielding 358 stars; 2.3° northeast is bright open cluster M 11, located at the border of the cloud.

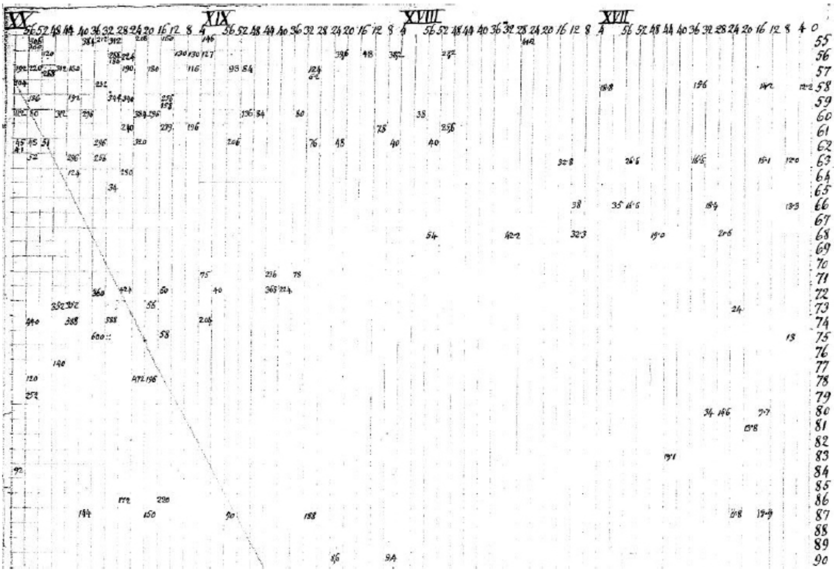


Figure 4-5: Chart of Caroline's 'Register of Gages', ranging from right ascension 16^h to 20^h and polar distance 55° to 90°; the numbers represent the star counts (the descending line refers to the galactic equator).

Sweeps 281–85, made from 5 to 7 October 1784, were special: the telescope was turned to the east (see section 2.2.6). Here the apparent motion of celestial objects was not horizontal, but inclines upwards, which made it difficult to determine positions. Nevertheless, seven nebulae were discovered and 14 gages performed; 12 were made in single fields, one in a half field and one covered 10 fields. With polar distances between 45° and 50°, the counts in Andromeda and Perseus were the most northerly so far.

With sweep 357 on 10 January 1785, Herschel had taken 689 gages, i.e. ten times more than for the 1784 paper. It was time for a new publication. However, due to hazy or damp conditions, six gages were rejected, leaving 683 for an analysis. 16% of them were derived from fractions of a field, 35% from single fields, 8% from combinations of 2 to 9 fields, 38% from combining 10 fields and 2% from combinations of 11 to 13 fields. Thus, the 10-field method, yielding an average over the full sweep breadth, had become the

standard.

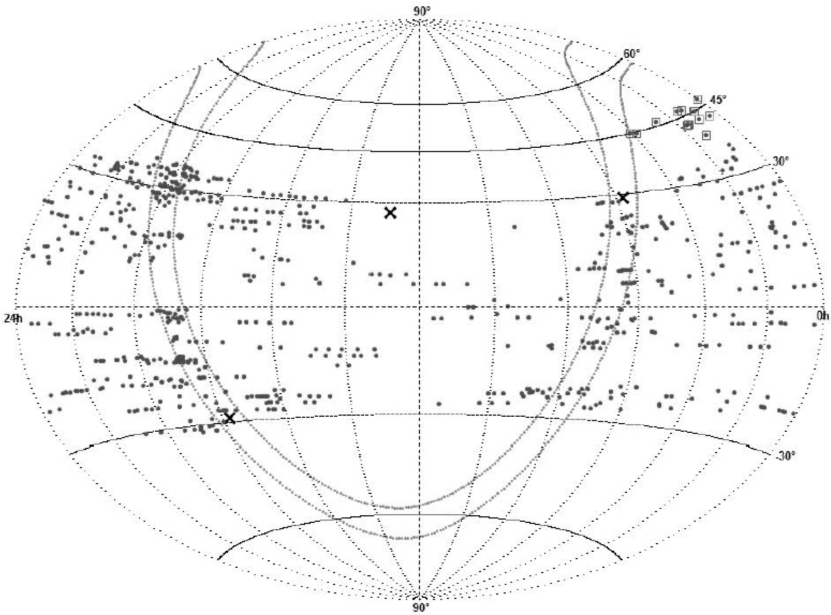


Figure 4-6: Distribution of the 683 gages, used for the 1785 paper. The highlighted points at upper right refer to the gages, made in the eastern sweeps of October 1784. The celestial band is the Milky Way; the two crosses inside mark the Galactic Centre in Sagittarius (lower left) and the anti-centre in Auriga (upper right); the central cross is the North Galactic Pole in Coma Berenices.951

William was convinced that the collected data were now sufficient to represent the star distribution in the 'stratum', though from his latitude (51.5°) about 30% of the Milky Way was not observable. Caroline had continuously plotted the star numbers in her 'Register of Gages' (Figure 4-5).952 The positions layed between PD 55° and 122° ($\delta = +35°$ to -32°). The most southern gage was made on 13 July 1784 in sweep 237; the single field in Sagittarius was 1° northeast of the globular cluster M 70. The place was only 5° above the horizon, a real challenge for counting stars (the result was 12). The 14 gages from the eastern sweep (PD 45° to 50°) were not plotted.

For the new paper, again titled 'On the Construction of the

Heavens', Herschel used 683 gages. It was read to the *Royal Society* on 3 February 1785.[953] Curiously, the text is signed 'Datchet near Windsor, January 1, 1785', too early a date, because the manuscript contains 22 gages made on 10 January.[954] Figure 4-6 shows the distribution of the 683 gages on the sphere. Beside the northern regions there were still large blank areas. The region in Coma Berenices, Leo and Virgo, near the North Galactic Pole (at 13^h, $+30°$), contained only a few gages. Here many nebulae were found, belonging to the 'stratum of Coma Berenices'. The sweeps, made to investigate the structure of this nebular 'stratum', left no time for star counts.

The paper of 1785 was revolutionary and goes well beyond that published a year before. Herschel initiated a field of astronomy, later called 'stellar statistics'. The text begins with a 'theoretical view' concerning the evolution of a system of stars distributed with near uniformity. Based on Newton's theory of gravitation, Herschel defines five 'forms' (I–V). These structures represent the possible results when stars of different sizes interact gravitationally:

I. relate to globular clusters,
II. to irregular clusters,
III. is a 'stratum of stars', built by "long extended, regular, or crooked rows, hooks or branches", IV describes a mix of stars and clusters,
IV. refers to so called 'vacant' regions.

I. Table of Star-Gages.

R.A.	P.D.	Stars.	Fields.	Memorandums.
H. M. S.	D. M.			
0 1 41	78 47	9,9	10	
0 4 55	65 36	20,0	10	
0 7 54	74 13	11,3	10	Moſt of the ſtars extremely ſmall.
0 8 24	49 7	60	1	
0 9 52	113 17	4,1	10	* The gages marked with an aſteriſk
0 12 52	113 17	3,2	10	* are thoſe by which fig. 4. tab.
0 16 48	67 44	11,9	10	VIII. has been delineated.
0 21 52	113 17	3,9	10	*
0 22 21	87 10	5,9	10	
0 28 26	46 54	60	1	
0 31 38	46 54	40	1	
0 33 33	65 32	20,4	10	
0 34 22	56 38	20	1	
0 35 22	55 38	24	1	
0 36 39	76 32	11,3	10	
0 39 56	78 43	8,1	10	
0 40 29	48 43	60	½	
0 44 21	87 10	7,6	10	
0 46 22	69 51	11	10	
0 46 33	65 32	13	10	
0 48 42	58 47	40	1	
0 48 50	58 13	17	1	
0 53 18	67 41	9,8	10	A little hazy.
0 53 40	45 37	73	1	
0 54 10	75 16	13	1	

Figure 4-7: The first rows of Herschel's 'Table of Star-Gages', contained in his paper of 1785 (see text).

Herschel's star count data are presented in the 'Table of Star Gages' of Chapter 4 (Figure 4-7). The 683 entries are sorted by AR; the positions of the (averaged) field centres refer to the 'time [equinox] of Flamsteed's Catalogue' (1690). The table also gives the (calculated) number of stars, the number of contributing fields (or parts), and remarks.

The gage data provided the observational basis to confirm Herschel's ideas about the structure of the Milky Way. His analysis is given in the section 'Problem'. Though the counts, of course, show the star distribution on the sphere, he had something greater

in mind: a three-dimensional view. This would reveal the form, structure and extension of the stellar system as a whole. Of course, this needed a still unknown quantity: distance.

But Herschel had a clever idea: “The stars being supposed to be nearly equally scattered, and their number, in a field of view of a known diameter, being given, to determine the length of the visual ray.” The basic assumption is that the stars are uniformly distributed in space (‘equally scattered’). Thus, there is a constant volume, containing just one star, and a unit distance to its nearest neighbour. He knew that this claim was valid only on large scales: “It may seem inaccurate that we should found an argument on the stars being equally scattered, when in all probability there may not be two of them in the heavens, whose mutual distance shall be equal to that of any other two given stars; but it should be considered, that when we take all the stars collectively there will be a mean distance which may be assumed as the general one.” Consequently, he rejected all gages in which “the stars happened either to be uncommonly crowded or deficient in number, so as very suddenly to pass over from one extreme to the other”. The latter was called ‘border-gage’; examples are given in sweep 243 (22 July 1784). Another rejected case was the ‘distance-gage’, defined in sweep 252 (18 August 1784): “By way of seeing how the stars were mixed I imagined them to be divided into four magnitudes and called them LL = very large; L = large; S = small; SS = very small this I did with a view to the distance of the stars and intended it for a Distance-Gage.”

Herschel further assumed that the stellar system had a boundary and that the ‘space-penetrating power’ of his 20-ft telescope was sufficient to show all stars within the limiting distance. Because they were thought to be uniformly distributed, he concluded that this distance was proportional to the number of stars in the field of view. This led to a distance formula, which is explained in modern terms here (Figure 4-8).

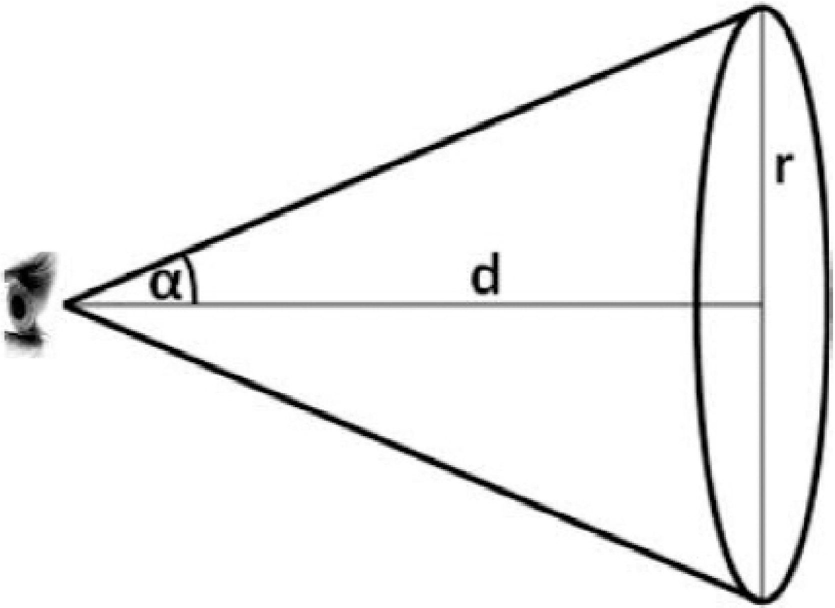


Figure 4-8: The observer at the telescope, located at left, views a cone in space. 2α is equal to the angular diameter of the field of view; the other parameters are explained below.

The parameters of the cone are:

d = distance to the boundary of the stellar system in the viewing direction (‘visual ray’)

r = radius of the cone at the boundary

α = cone angle (2α = field of view = 15' for the standard eye-piece)

With r and d, the cone volume is $V = \frac{1}{3}\pi r^2 d$. Using the trigonometric relation r = d · tan α, one can eliminate r to get (1): $V = \frac{1}{3}\pi d^3 (\tan\alpha)^2$. Let N be the number of stars, counted in the field of view. If the star density is constant, they are homogeneously distributed over the entire cone. Therefore, the volume V is proportional to N. One now defines a unit volume V_0, containing 1 star; its radius is the assumed as the distance to the next neighbouring star. Thus, we have N stars in the volume: $V = N \cdot V_0$,

from which we get N = V/V_0 or simply N = V, when V is measured in unit volumes. Solving (1) for the distance d, we finally have (with V = N):

$$d = \left[\frac{3N}{\pi(\tan\alpha)^2}\right]^{\frac{1}{3}}$$

This is the distance to the star at the boundary, in units of the distance between two neighbouring stars. Herschel took the Sirius distance as the unit (the brightest star was also thought to be the nearest).[955] The formula shows that for a fixed field of view (fixed α), d depends only on the number of stars $d \sim \sqrt[3]{N}$. The function d(N) is called ‘Herschel’s ray-function’. The paper of 1785 gives a table of its values (Figure 4-9); Figure 4-10 shows the graph of the function. Note that Herschel did not assume that all stars in the system had the same luminosity.[956]

TABLE II.

Stars in the field	Viſual ray.	Stars.	Ray.	Stars.	Ray.	Stars.	Ray.	Stars.	Ray.
		31	186	71	245	210	352	700	527
0,1	27	32	188	72	246	220	358	800	551
0,2	34	33	190	73	247	230	363	900	573
0,3	39	34	192	74	249	240	368	1000	593
0,4	43	35	193	75	250	250	374	10000	1280
0,5	46	36	195	76	251	260	378	100000	2758
0,6	49	37	197	77	252	270	383		
0,7	52	38	199	78	253	280	388		
0,8	54	39	201	79	254	290	393		
0,9	56	40	202	80	255	300	397		

Figure 4-9: Herschel’s table shows the values for the ‘visual ray’ d, measured in units of the Sirius distance.

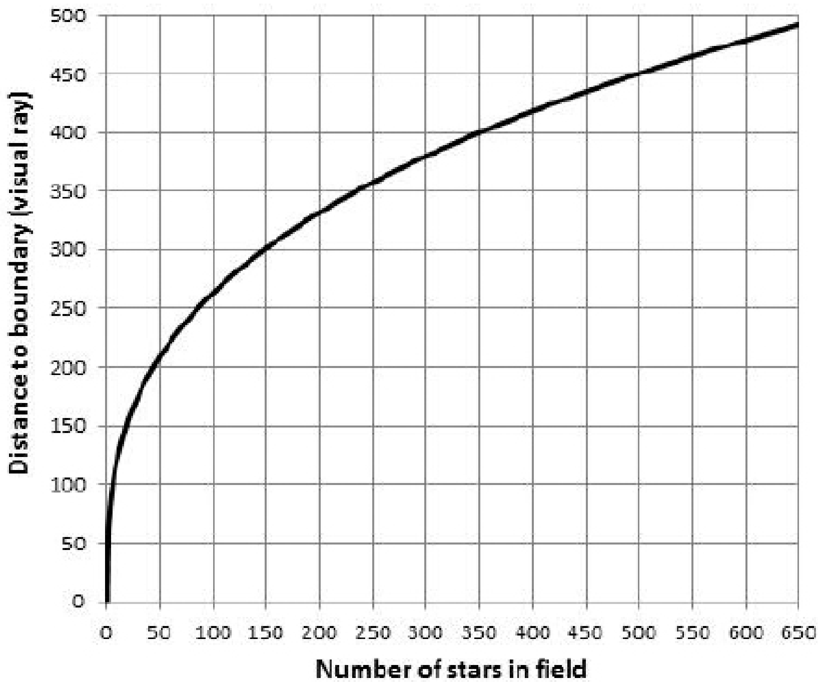


Figure 4-10: Plot of 'Herschel's ray-function', termed d(N) here.

By the star gages, Herschel now had – based on his assumptions – a distance value for each observed field on the sphere. From this information, a three-dimensional view of the stellar system could be drawn. Because it was impractical for him to create a graphical representation for the full dataset, he chose a representative sample. Herschel took gages, lying on a great circle, limited by the most northerly/southerly PD of the fields. This figure represents a section of the stellar system. Of course, it would have been ideal to take the great circle formed by the band of the Milky Way, but this was not realizable: the part north of about 30° declination was not yet swept and that south of -30° was not observable.

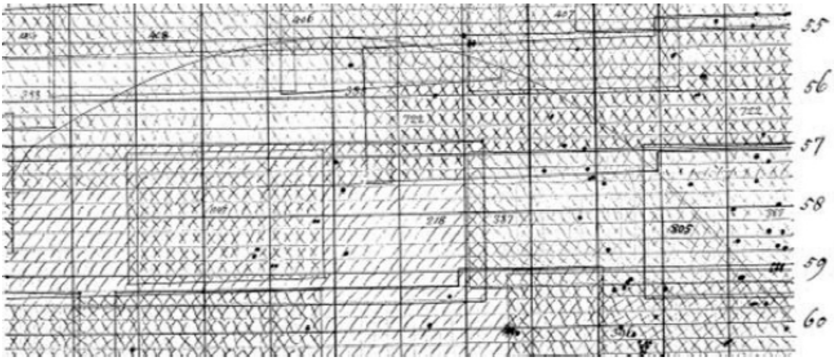


Figure 4-11: Caroline's 'Register of Sweeps' shows the section (curved line) from AR 12^h to 16^h and PD 55° to 60°.

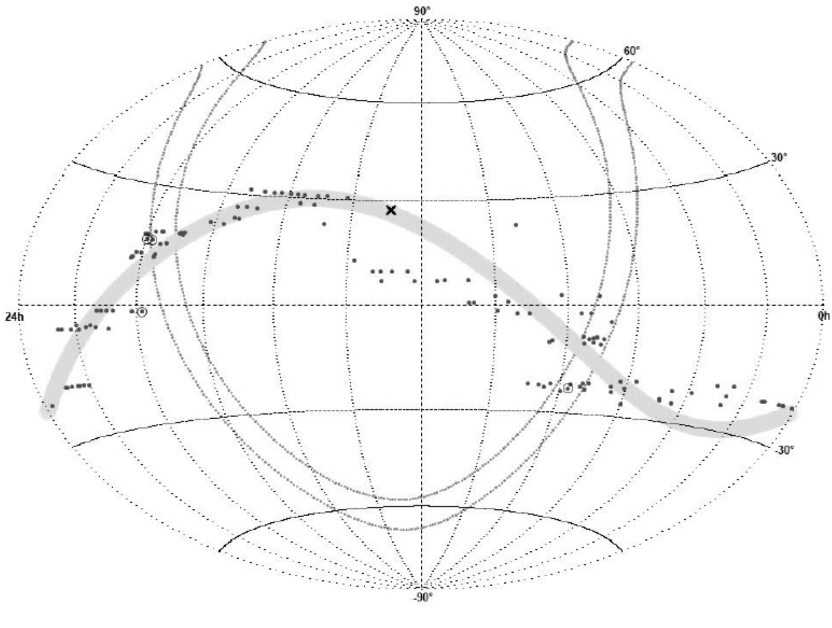


Figure 4-12: Herschel's section data on the sphere (the small circles are explained in the text).

Using Caroline's 'Register of Gages', William defined a suitable circle on the sphere: "I have taken one which passes through the poles of our system, and is at rectangles [right angles] to the conjunction of the branches which I have called its length. The name of the poles seemed to me not improperly to those which are

90 degrees distant from a circle passing along the milky way, and the north pole is here assumed to be situated in R.A. 186° and P.D. 58°." The section "makes an angle of 35 degrees with our equator, crossing it in 124½ and 304½ degrees". Caroline had also plotted parts of the section on the 'Register of Nebulae', showing the sweep areas (Figure 4-11).957 The data were taken from 127 gages, marked by an asterisk in Herschel's table (Figure 4-7). The distribution of the sample on the sphere is shown in Figure 4-12. Due to the lack of data, there is a considerable deviation in some parts. Of course, Herschel wanted to 'fill' the circle as soon as possible (which was never done).

After defining a longitude along the great circle, Herschel transformed the gage positions (AR, PD) to this coordinate. For the sake of simplicity, the latitude was set to zero (projection on the circle plane). This naturally leads to a planar plot of the distances in polar coordinates. To show the result of the calculations, he drew a graphical representation: the famous and often copied 'Fig. 4'. Figure 4-13 shows both the draft version (contour only) and the published one (filled with 'stars').958 The Sun (origin of the coordinate system) is shown in both figures.

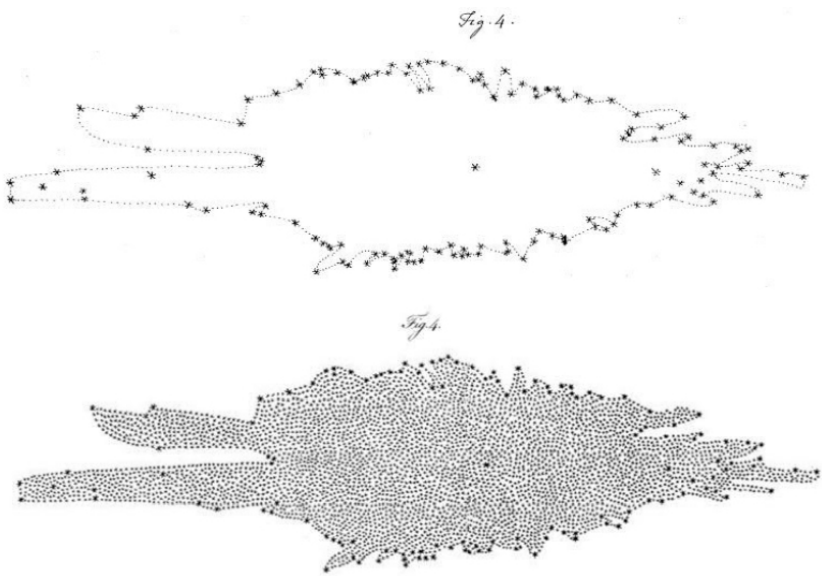


Figure 4-13: Herschel's plot of the Milky Way section (singular

point = Sun); top: draft version, bottom: published version.

Using the star count data and the ray-function d(N), one can reproduce Herschel's figure (Figure 4-14). However, the comparison shows some differences. The double peak at the left lies at the intersection with the Milky Way above the equator in Sagitta (588 stars counted); the right peak is at the intersection below the equator in Puppis (204 stars). Both are marked by circles in Figure 4-12. Herschel ignored the cut seen between the Sagitta peaks (also marked). This gage (62.2 stars) was taken in Aquila, below the section. The effect is due to the projection on the section plane. Herschel was aware of this fact and smoothed the boundary by interpolation. Also interesting are the minimum (56 stars) above the Sagitta peaks and the following second maximum (368 stars). This marks the Great Rift in the Milky Way, where a branch goes off the main band from Sagitta in the direction of Ophiuchus. We now know that the decrease of star numbers is due to dust clouds, absorbing much of the light in the line of sight.

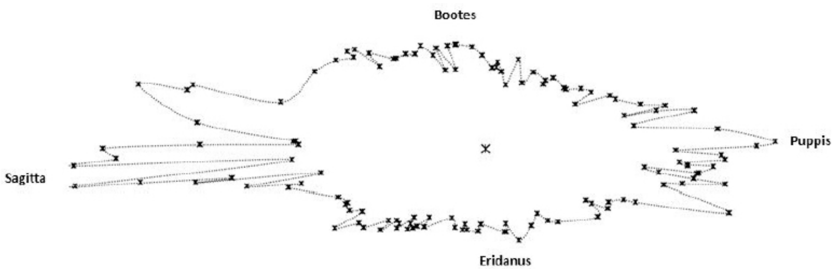


Figure 4-14: A modern reproduction of Herschel's section of the Milky Way shows slight differences.

What is the relation between Herschel's section and his representation of the 'stratum' in the 1784 paper (Figure 4-13)? The section refers to a plane perpendicular to the block-shaped, spitted stratum, as shown in Figure 4-15. A more realistic picture is presented in Figure 4-16 – the orientation of Herschel's section of the galaxy. By rotating the plane around its vertical axis, one gets different sections; for instance, one passing through Perseus/ Scorpius (90° rotation). Clearly, Herschel had chosen an angle so that one intersection with the Milky Way lies in Sagitta (between Cygnus and Aquila), where the maximum star number (588) was

registered.

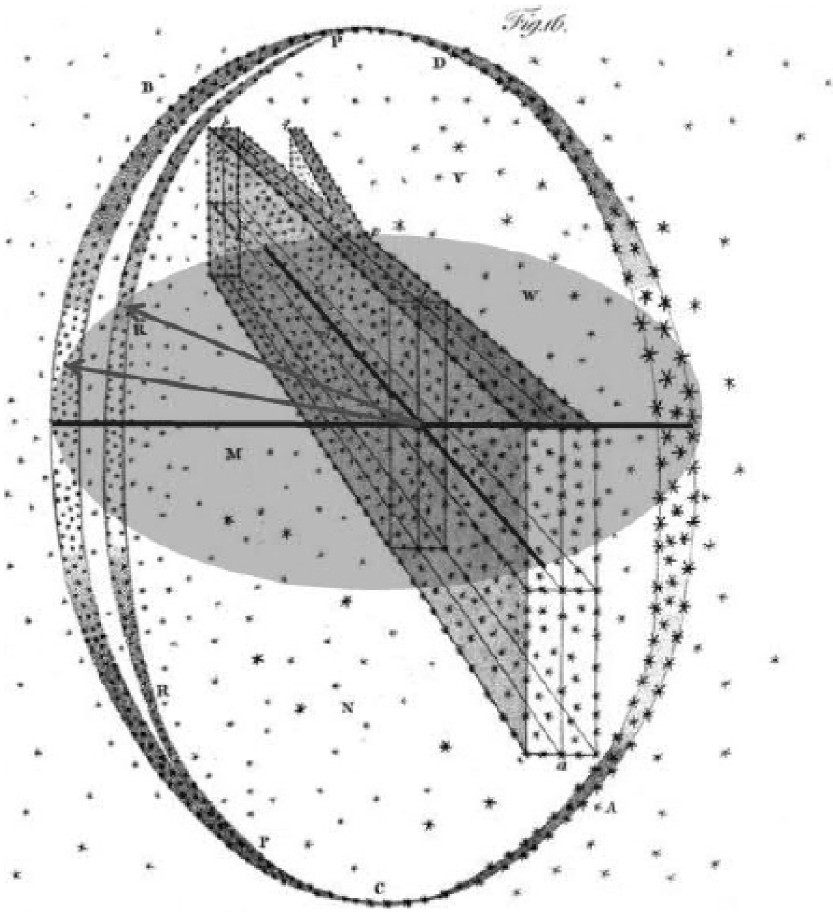


Figure 4-15: Location of Herschel's section (grey circular area) relative to the block-shaped, spitted stratum (here the published version is shown, clearer marking the Sun's position). The subdivision, shown in the section, is indicated by the two arrow lines.

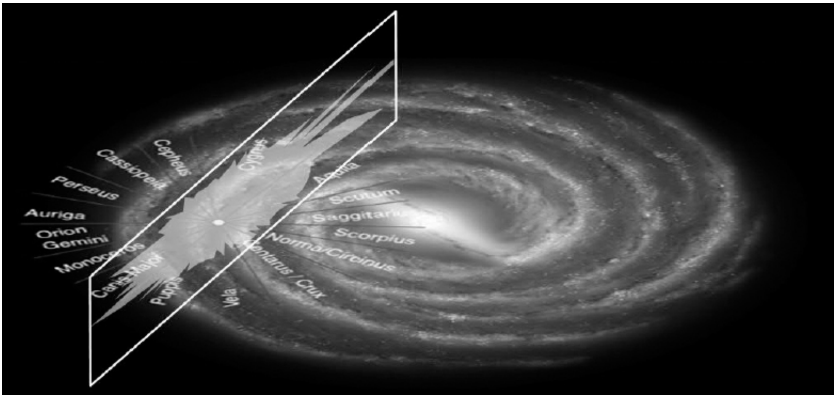


Figure 4-16: Orientation of Herschel's section in the Milky Way (the size of the rectangle is not important).

The extent of the section is measured in units of the (unknown) Sirius distance. The rays to the borders are: Sagitta 497, Puppis 349, Boötes 122, Eridanus 108 (see Figure 4-14). Thus, we get a horizontal extent of 846 units and a vertical extent of 230 units. Taking modern distances, Herschel's plot covers only a small neighbourhood of the Sun. Assuming a limiting magnitude of about 14 for the counted stars, he could see sun-like stars to about 2000 light-years. This is one tenth of the actual distance to the nearest edge of the Milky Way in the chosen orientation.

Anyway, the confined view from inside a flattened stellar system ('stratum of stars') is correct. In Herschel's words: "we inhabit the planet of a star belonging to a compound nebula of the third form [containing] many millions of stars". It is important to stress that his 'Fig. 4' does not show our Galaxy! This wrong interpretation often appears in the literature (see section 4.1.6). However, it may be interesting to create a section in the plane of the Milky Way. The author has produced such a planar view of the galactic 'boundary'. Due to the observational limits of Herschel's method, it does not show any significant structure.

4.1.3. Further gages and the paper of 1802

After sending the manuscript to the *Royal Society* in early January 1785, Herschel continued the star counts on the 27th (sweep 358).

Two 10-field-counts were made in Eridanus giving low numbers (7.4 and 9.8); haziness terminated the observation after half an hour.

Except the few eastern sweeps of October 1784, all were made for $\delta < +35^{\circ}$ (PD $> 55^{\circ}$). To get the position of a new object or field centre, a reference star was needed. March brought an innovation: the telescope was now able to reach higher elevations. Thus, Caroline expanded her list of Flamsteed stars, arranged in PD zones of 1° width. On the 17th (sweep 389) Ursa Minor was observed. The night brought one 5-field- and two 10-field counts with low values (11.6, 10.1, 15.5). Another innovation was tested in sweep 600 (22 September 1786): the front-view. A gage in Cygnus was made with the new design in that sweep, another one in sweep 612 (Pegasus).

Herschel published nothing new about gages until 1795. Meanwhile the frequency of star counts had markedly decreased. The paper mainly concerns the Sun, but at the end, four remarkable gages are mentioned.[959] They were made on 22 August 1792 in sweep 1024, covering an area from Aquila to Delphinus. Herschel was impressed by the great number of stars. For instance, he first counted 150 stars in a quarter field, giving 600 for the whole; this density remained over 16 minutes. He calculated the total number of stars to be 133,095. In the same manner he determined 36,601 stars over the next six minutes, followed by 74,889 over 15 minutes and 14,419 over four minutes. Thus, in 41 minutes 258,981 stars had passed. This result was worth publishing.

The last gages were made in sweep 1111 on the 26 September 1802 (two single fields in Draco). Four days later, Herschel's sweep campaign ended with no. 1112. From the first gage in sweep 55 (19 December 1783) to the last, we have 1091 star counts in total, made in 265 sweeps (Figure 4-17). One can divide the mission into two periods. The first relates to the 683 gages, used in the 1785 paper; the second to the remaining 402. In total, Herschel counted more than 88,000 stars in 5567 fields. It should be noted that a gage is a star count giving a number greater than 0. Fields with zero result were called 'vacant' by Herschel (see section 4.1.5).

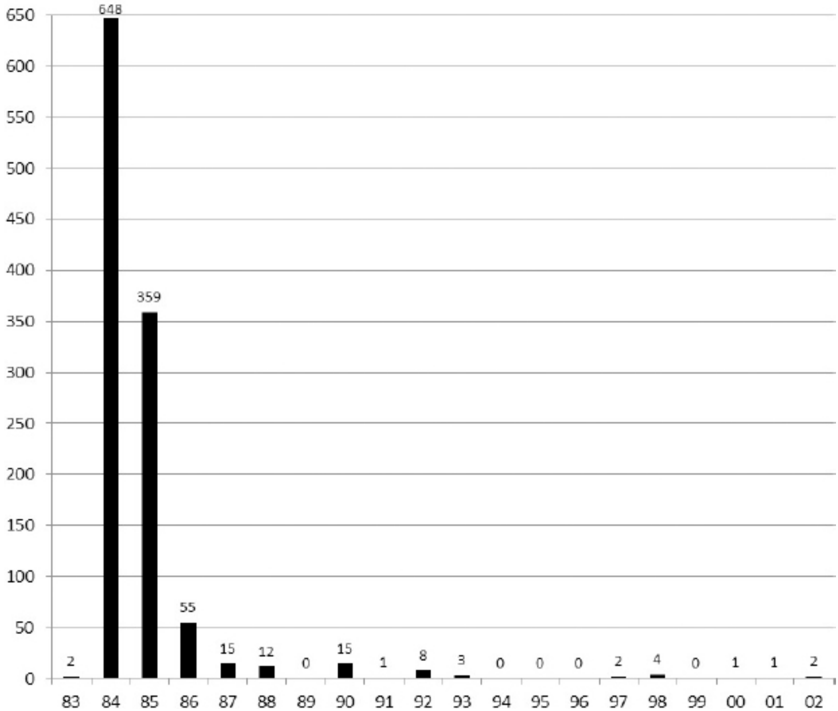


Figure 4-17: Annual number of gages 1783–1802. After the paper of 1785, Herschel's interest in star counts dropped significantly.

Herschel did not publish the gages, taken after the 1785 paper. This was done 100 years later by Holden at Wasburn Observatoy. Volume II of the institute publications contains two tables.960 The first lists the 683 published gages, the second "405 unpublished gauges", resulting from sweeps 358–1112. In total, we have 1088 gages with 1860 positions (less than Caroline's 1091, taken from the sweep records). The source for the second table is given: "Lieut. Col. John Herschel kindly undertook the search for the unpublished gauges, and I owe to him and to Miss Rose Herschel a complete copy of the *ms* [manuscript] by Miss Caroline Herschel, in which these are given, and also a list in which they are arranged in order of R.A."961 Holden quotes a handwritten note of Caroline:

The following gages begin with the 358 sweep. As far as 357 sweep, they are printed in the paper on the Construction of the Heavens and their places have been given in Flamsteed's time and polar

distance. But these gages are calculated for the time when the observations were made, though as far as the 438 sweep, the places are down in the journals in Flamsteed's time and P.D. But every gage is calculated twice, and after having been brought to the time of observation carried into this book.

Up to sweep 439, Caroline determined positions for the equinox 1690. Starting with the next one (24 September 1785), they were "calculated for the time when the observations were made". The date was not ambiguous: it marks the successful installation of the 'PD clock', which allowed the polar distance to be read directly at Caroline's desk. The new device was more accurate and her brother took the opportunity to change to a new equinox (of date).

It is interesting that Dreyer presents Holden's second table in an appendix to the *Scientific Papers*, titled 'Star-Gages from the 358th to the 1111th Sweep'.962 The date of observation and a few remarks were added. He wrote: "The table is here printed from Caroline Herschel's MS." Caroline mentions in her 'Temporary Index' that when observations "which belong to Planets, Double Stars, Nebulae, Comets and Star gages are looked for, their respective books and parcels must be consulted".963

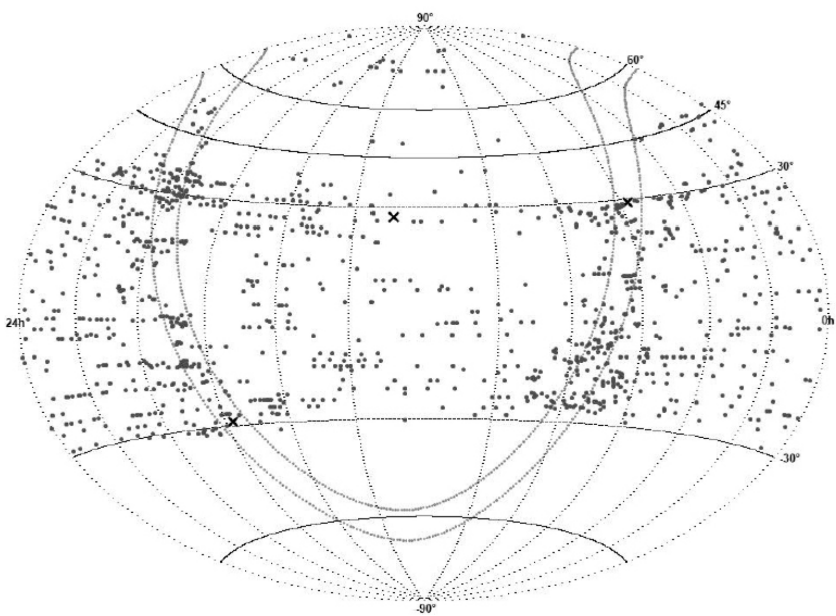


Figure 4-18: Map of all 1091 gages, made from December 1783 to September 1802.

Figure 4-18 shows the distribution of all gages on the sphere. Most lie between declination +30° and -30°. There is a certain crowding in the Cygnus Milky Way at 20^h, +30°; about 40 gages were taken here. Among them is that with the highest number of stars in a field: 612, counted in sweep 1027 on 15 September 1792. Notable gages are collected in Table 4-2.

Sw	Date	Fields	Gage	Con	Remarks
55	19 Dec. 1783	1	60-70	Mon	first gage (Datchet)
185	27 Mar. 1784	1	24	Her	first gage off the Milky Way
190	12 Apr. 1784	4	9.5	Ser	first multiple field count
191	13. Apr. 1784	13	4.6	Vir	maximum number of fields (first appearance)
206	24 Apr. 1784	12	18.6	Oph	58 gages made for the 1784 paper
210	9 May 1784	10	8.1	Vir	first 10-field count
222	21 May 1784	10	0.5	Sco	minimum number ('hole in Scorpius' near M 80)
228	16 Jun. 1784	0.5	422	Sct	first ½ field counted
232	24 Jun. 1784	1	84	Sgr	gage near Galactic Centre
237	13 Jul. 1784	1	12	Sgr	most southern gage (-32°)
238	15 Jul. 1784	10	11.1	Aqr	maximum number of gages in a sweep (38)
254	23 Aug. 1784	0.25	588	Sge	maximum number so far
282	5 Oct. 1784	10	28.1	And	first eastern gage (of 14 until 7 October)
357	10 Jan. 1785	10	11.1	Hya	683 gages, used in the 1785 paper
358	27 Jan. 1785	10	7.4	Eri	first 'unpublished' gage
360	29 Jan. 1785	0.5	245	Aur	gage near Galactic Anti-Centre
389	16 Mar. 1785	5	11.6	UMi	first gage north of PD 45° (new star table)
393	6 Apr. 1785	10	5.3	Com	gage near the North Galactic Pole
418	1 Aug. 1785	5	26.2	Sgr	first gage at Clay Hall
523	15 Feb. 1786	5	18.6	Dra	thousandth gage
445	28 Sep. 1785	10	5.6	Aqr	equinox changed from 1690 to 1785
558	20 Apr. 1786	10	6.8	Vir	first gage at Slough
600	22 Sep. 1786	0.25	220	Cyg	first gage with the front-view
1027	15 Sep. 1792	0.25	612	Cyg	maximum number
1056	5 Oct. 1793	0.5	80	Aql	last gage bevor 1795 paper
1111	26 Sep. 1802	1	25	Dra	last gage (1091); most northern gage (+80°)

Table 4-2: Notable gages; the sweep number relates to the gage were a new situation appeared first.

4.1.4. The death of Herschel's section

After the sweep campaign, Herschel had time for an astronomical resume. He published five papers in the *Philosophical Transactions* treating (among other themes) the structure of the Milky Way, based on his observations of stars, double stars, star clusters and

nebulae (see section 4.2 for the papers of 1811–18).

Section 'Enumeration of the parts that enter into the construction of the heavens' in Herschel's third catalogue concerns the Milky Way.[964] A major subject are star clusters, collected in classes VI–VIII. He had discovered 197, of which 172 (86%) lie in the band of the Milky Way at galactic latitudes between +15° and -15° (Figure 4-19); only 14% are outside. Because there were so many objects in such a narrow region, Herschel doubted his former assumption of equally scattered stars (constant density). We see this already in sweep 765 (14 October 1787), made in Lacerta: "It is very evident in this part of the heavens, that there is some distance between us and the milky-way not equally scattered over with stars." There are other sweeps that both recorded gages and discovered star clusters. For instance, in sweep 934 (4 March 1790), Herschel found four open clusters and took 10 gages in the central Milky Way of Canis Major and Puppis, yielding numbers between 129 and 286.[965]

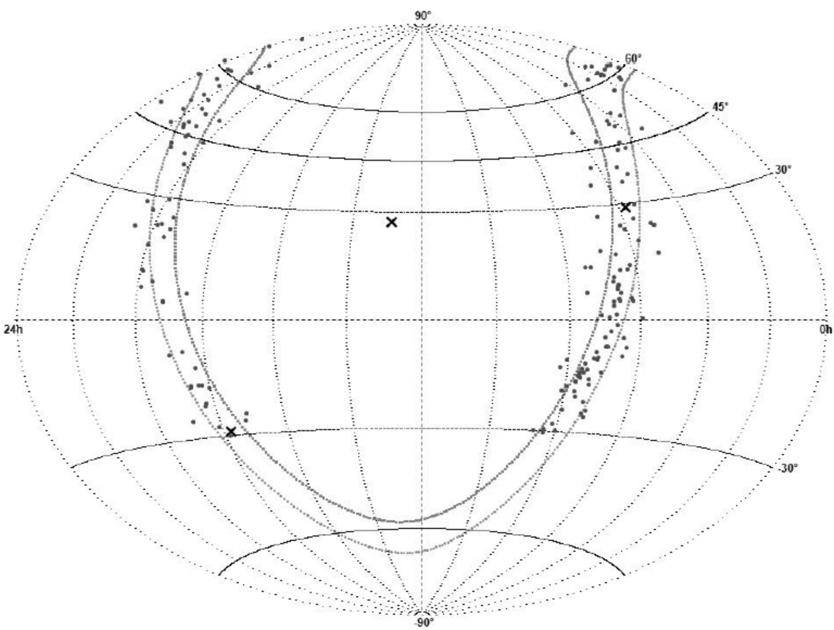


Figure 4-19: The 172 star clusters of Herschel's classes VI–VIII, located in the band of the Milky Way.

Obviously, the 'stratum' of the Milky Way was generally a mix of

stars (single, double, multiple) and star clusters, thus far from being a uniform structure. The observational facts undermined Herschel's basic assumption of a constant star density, used in the 1785 paper to determine the size of the stellar system. He wrote: "On a very slight examination it will appear that this immense starry aggregation is by no means uniform. The stars of which it is composed are very unequally scattered, and show evident marks of clustering together into many separate allotments."

In addition, observations with the 40-ft had shown that another assumption was untenable: that the 20-ft shows all the stars to the limit of the stellar system, i.e. there was nothing beyond that. With the great reflector, Herschel could see many more stars in a certain direction – its greater 'power of penetrating into space' pushes the boundaries! In the paper of 1811 Herschel wrote:[966]

I must freely confess that by continuing my sweeps of the heavens my opinion of the arrangement of the stars […] has undergone a gradual change; and indeed when the novelty of the subject is considered, we cannot be surprised that many things formerly taken for granted, should on examination prove to be different from what they were generally, but incautiously, supposed to be. For instance, an equal scattering of the stars may be admitted in certain calculations; but when we examine the milky way, or the closely compressed clusters of stars, of which my catalogues have recorded so many instances, this supposed equality of scattering must be given up.

In the next publication (1814), Herschel again discussed the structure and content of the Milky Way.[967] He confirmed that our stellar system is not a mere 'stratum' of individual stars but a mix of stars and star clusters of various forms (e.g. aggregations of stars, irregular clusters, globular clusters). He explicitly mentions 157 objects, writing:

The milky way is generally represented in astronomical maps as an irregular zone of brightness encircling the heavens, and my star gages have proved its whitish tinge to arise from accumulated stars, too faint to be distinguished by the eye. The great difficulty of giving a true picture of it is a sufficient excuse for those who have traced it on a globe, or through the different constellations of an

Atlas Coelestis, as if it were a uniform succession of brightness. It is, however, evident that, if ever it consisted of equally scattered stars, it does so no longer

Three years later, Herschel wrote in the 1817 publication:968

In addition to 863 [683] gages already published [1785], above 400 more have been taken in various parts of the heavens, but with regard to these gages, which on a supposition of an equality of scattering were looked upon as gages of distances, I have now to remark that, although a greater number of stars in the field of view is generally an indication of their greater distance from us, these gages, in fact, relate more immediately to the scattering of stars, of which they give us a valuable information, such as will prove the different richness of the various regions of the heavens … I have now to remark that, although a greater number of stars in the field of view is generally an indication of their greater distance from us, these gages, in fact, relate more immediately to the scattering of the stars, of which they give us a valuable information, such as will prove the different richness of the various regions of the heavens … By these observations it appears that the utmost stretch of the space-penetrating power of the 20 feet telescope could not fathom the Profundity of the milky way.' Herschel writes that the 40-ft reflector 'would then probably leave us again in the same uncertainty as the 20 feet telescope.

Examples from 11 sweeps, made between 1784 and 1792, are given.

In Herschel's last paper on the subject, published in 1818, we read: "The milky way, at the profundity beyond which the gaging powers of our instrument cannot reach, is not an ambiguous object."969 The term 'ambiguous' is explained in the text: "When the nature or construction of a celestial object is called ambiguous, this expression may be looked upon as referring either to the eye of the observer, or to the telescope by which it has been examined." Based on examples from four sweeps, made between 1786 and 1790, Herschel concludes: "Celestial objects can only be said to remain ambiguous, when the telescope that have been directed to them leave it undetermined whether they are composed of stars or of nebulous matter." He eventually wrote:970 "when our gages will no

longer resolve the milky way into stars, it is not because its nature is ambiguous, but because it is fathomless." This sounds like a capitulation – and it means the end of his famous Milky Way section of 1785.

Though the star gages turned out to be useless to reveal the structure and dimensions of the stellar system (Milky Way), the method was not: William Herschel opened the field of 'stellar statistics'.[971] John took things further during his survey of the southern sky at Feldhausen, where the Milky Way looks much more impressive (crossing the zenith). This led to a modification of the old 'stratum of stars'. But still another point became significant: William's detection of 'vacant places', i.e. fields without stars.

4.1.5. 'Vacant places' and the famous 'hole in Scorpius'

In sweep 54 on 19 December 1783 – the night of the first star gage – Herschel noticed "many vacant places" in southern Taurus. In sweep 78 (17 January 1784), he even found "the longest vacant space I ever have seen", located in the northern part of the constellation (Figure 4-20). The same happened 11 days later in sweep 131 (Virgo). Unfortunately, no coordinates are given for the remarkable places. The shortcoming has been remedied on 12 April. In sweep 189, a gage was taken in Boötes, showing "about 5 or 6 stars generally in the field". Then seven sweep paths, spread over about one hour of time, brought "many fields without stars". Now Herschel determined the position of this 'void in Boötes'.

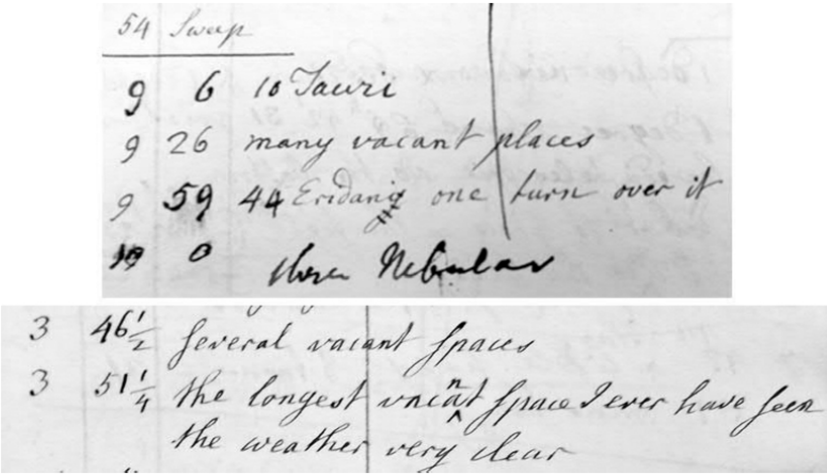


Figure 4-20: Top: Herschel's first 'vacant places', seen on 19 December 1783 in sweep 54. Bottom: 'Vacant space' in sweep 78 on 17 January 1784.[972]

In sweep 212, Herschel performed two gages in Scorpius. M 80 was the last observed object, noting "very bright … must be visible with an achromatic".[973] In sweep 215 the bright globular cluster was not observed. After a gage over two fields (yielding 32.5), three bright stars were seen. The first ("star not in Fl") is actually 19 (o) Sco (the revised sweep record gives the correct identification), the second is ρ Oph (called 'g Serpentarii') and the third 22 Sco. The short sweeps contain no hint of a 'hole'.

The crucial observation was made in sweep 222, starting in the night of 21 May. The scene was the Scorpius/Ophiuchus border. In the long sweep, Herschel made 14 gages. Four minutes after he met M 80 (at 0:15 am on the 22nd), the star 19 Sco was seen and used as reference star. The following gage, taken at 0:20 am, brought a mean star number of only 0.5. It was calculated from 10 fields along the sweep path: 0 . 2 . 0 . 0 . 1 . 1 . 0 . 0 . 0 . 1 = 5/10 = 0.5; the mean position (for 1690) was later determined by Caroline: AR 16 04 19, PD 113 06 (Table 4-3). The next gage brought a value of 0.7. Then 'g Serpentarii' (ρ Oph) entered the field.[974] The next three gages yielded 1.1, 1.4 and 1.8 ("in all appearances perfectly clear"). The following note reads: "I see the 19 Scorpii & g Serpen[tarii] & 22 Scor[pii] very plainly with my naked eye". The

relevant five gages were performed in about 10 minutes; at that time the sky area was only 13° above the horizon (Table 4-3).

AR	PD	Number	Herschel's notes
16 04 19	113 06	0.5	perfectly clear
16 06 28	113 04	0.7	perfectly clear
16 09 28	113 04	1.1	perfectly clear
16 11 28	113 04	1.4	the same
16 13 28	113 04	1.8	g Serpentarii and 19 Scorpii visible to the naked eye

Table 4-3: Extract from Herschel's 'Table of Star-Gages' (published 1785), relating to the vacancy near M 80. The star numbers are the mean over 10 fields.

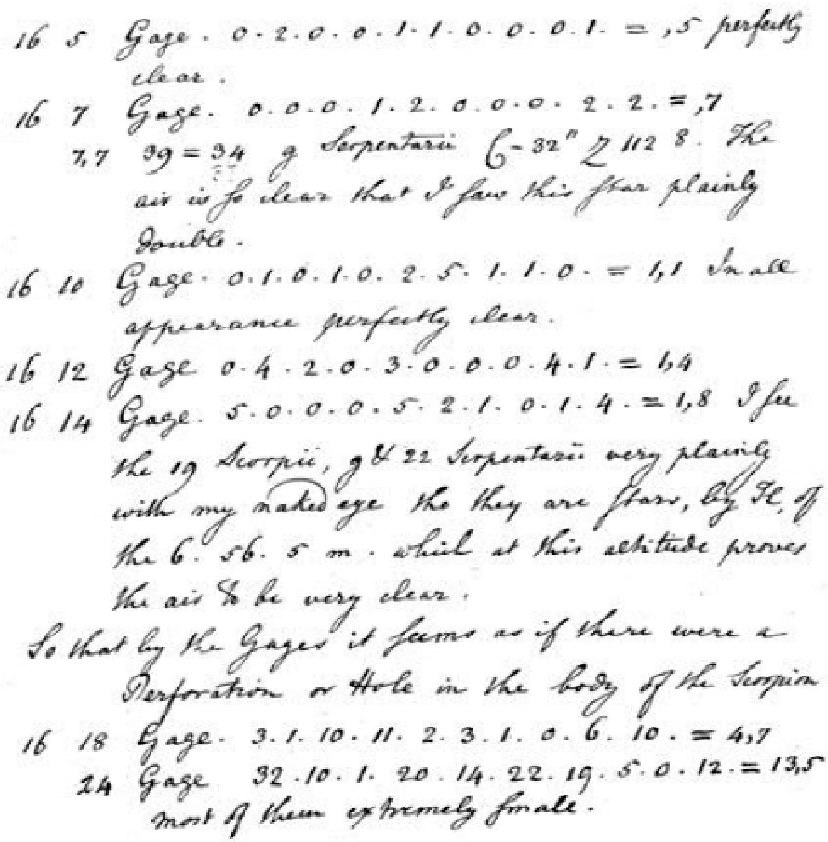

16 5 Gage. 0.2.0.0.1.1.0.0.0.1. = ,5 perfectly
clear.
16 7 Gage. 0.0.0.1.2.0.0.0.2.2. = ,7
7,7 39 = 34 g Serpentarii 6 - 32" 2 112 8. The
air is so clear that I saw this star plainly
double.
16 10 Gage. 0.1.0.1.0.2.5.1.1.0. = 1,1 In all
appearance perfectly clear.
16 12 Gage 0.4.2.0.3.0.0.0.4.1. = 1,4
16 14 Gage. 5.0.0.0.5.2.1.0.1.4. = 1,8 I see
the 19 Scorpii, g & 22 Serpentarii very plainly
with my naked eye tho' they are stars, by Fl. of
the 6. 56. 5 m. which at this altitude proves
the air to be very clear.
So that by the Gages it seems as if there were a
Perforation or Hole in the body of the Scorpion
16 18 Gage. 3.1.10.11.2.3.1.0.6.10. = 4,7
24 Gage 32.10.1.20.14.22.19.5.0.12. = 13,5
most of them extremely small.

Figure 4-21: In sweep 222 of 21 May 1784, Herschel's saw a 'hole in the body of the Scorpion'; the naked-eye star 'g Serpentarii' is

now called ρ Oph (from *Journal No. 9*).

The term ‘hole’ is missing in Caroline’s *Sweeps No. 3*; William’s *Journal No. 9* gives more data (Figure 4-21). Now the globular cluster in Ophiuchus is correctly identified as “Messier 80 Neb.”. More important is the enhanced note on 19 Sco: “I see the 19 Scorpii & g Serpentarii & 22 Scor[pii] very plainly with my naked eye they are of the 5, 5-6 & 6 magnitudes, which at this altitude shews the air to be very clear. So that by the Gages it seems as if there were a hole in the Scorpion.”[975] Figure 4-22 shows the area. In the final record version, we read “a Perforation or Hole” and Caroline gives the positions of the five gages for 1800.[976] However, the AR of the first is 4^m too large (16 14 50 instead of 16 10 50) and the PDs of the first two are too large by 4’ and 6’ (113 27 for both instead of 113 23 and 113 21, respectively). These might be typos; a rare event, because Caroline’s calculations usually are correct.

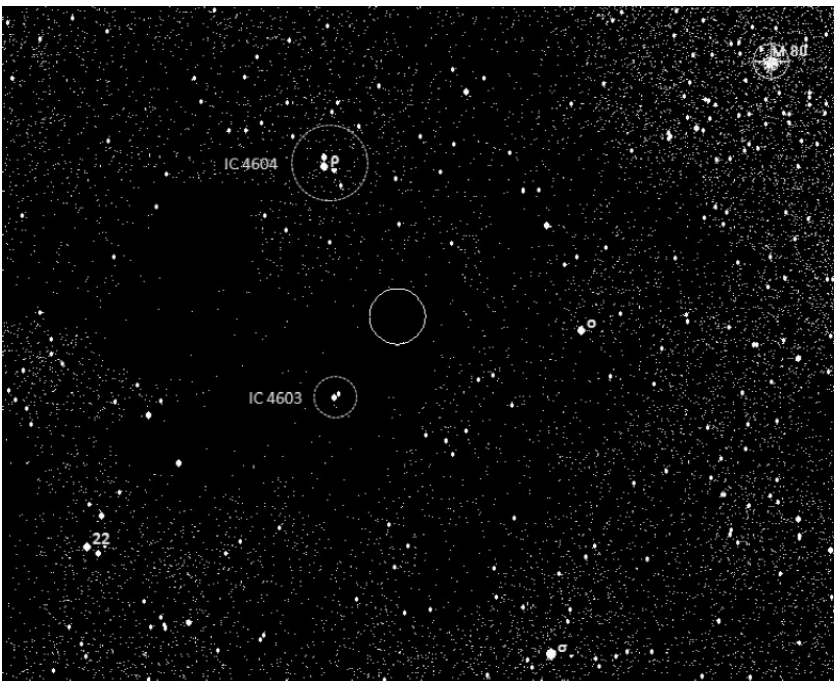


Figure 4-22: Herschel’s ‘hole’ in Scorpius, exactly at the border to Ophiuchus and about 1.7° southwest of the globular cluster M 80.

The circle shows the central field (of 10) on the sweep path. The four bright stars are σ & o Sco and ρ & 22 Oph. Herschel missed the reflection nebulae IC 4603 and IC 4604 (ρ Ophiuchi Nebula); their sizes are given by the dotted circles.

Herschel gives a size of "at least 4 degrees", but by the chart it is about 2°. Due to the sweep method, he could not overlook such areas (sweep 222 breadth = 2°). So the size is an extrapolation. He was so impressed by the case that he dedicated a section in his 1785 paper to it: 'An opening in the heavens'.[977] There we read:

Some parts of our system indeed seem already to have sustained greater ravages of time than others, if this way of expressing myself may be allowed; for instance, in the body of the Scorpion is an opening, or hole, which is probably owing to this cause. I found it while I was gaging in the parallel from 112 to 114 degrees of north polar distance. As I approached the milky way, the gages had been gradually running up from 9,7 to 17,1; when, all of a sudden, they fell down to nothing, a very few pretty large stars excepted, which made them shew 0,5, 0,7, 1,1, 1,4, 1,8; after which they again rose to 4,7, 13,5, 20,3, and soon after to 41,1. This opening is at least 4 degrees broad, but its height I have not yet determined. It is remarkable, that the 80th *Nebuleuse sans étoiles* of the *Connaissance des Temps* [M 80], which is one of the richest and most compressed clusters of small stars I remember to have seen, is situated just on the western border of it, and would almost authorize a suspicion that the stars, of which it is composed, were collected from the place, and had left the vacancy.

In the long sweep 223, performed in the following night, Herschel found a second 'hole' in Scorpius, about 4° south of the first and near to the globular cluster M 4, located 1.3' west of Antares. North of it, the mean star numbers dropped down to 1.6, 2.0 and 3.8; soon after he discovered the globular cluster NGC 6144 (VI 10), 18' away. He does not use the term 'hole', but it appears when the vacant place was seen again in sweep 224: [978] "The two next fields above the gage going up the second time were again 0. 0. So that the border of the hole is thereby pointed out." Sweep 224 also brought the discovery of VII 7 = NGC 6520, a small open cluster. Not really remarkable, if it wasn't only 9' southeast of the striking

dark nebula B 86 (Figure 4-23). The ‘object’ is not mentioned, though it certainly was in Herschel’s field of view.979 The reason why he missed it, is simple: “daylight very strong”. The sweep is marked ‘half swept’. This term means it was (at least partly) influenced by twilight, moonlight, haze or anything similar. However, this attribute is often not used very strictly. For instance, sweep 222 started with “strong daylight” but at 10:00 pm it was “pretty dark” and about 0:20 am the sky became “perfectly clear”; at 1:00 am “twilight very strong” is noted. Thus, Caroline’s attribute ‘half swept’ is justified for only one third of the 4.5-hour sweep.

Figure 4-23: The coarse open cluster NGC 6520 in Sagittarius, discovered on 24 May 1784. The nearby dark nebula B 86 was not seen.

In sweep 566 (26 May 1786) no gages were taken, but Herschel detected some vacant places (“the night very fine”). They appeared a few minutes after his observation of the globular cluster M 80. Caroline positions match those of sweep 222. However, sweep 566 was about 1° more north, so that only the northern part of the hole

was seen. The notes do not mention the former sweep. Finally, in sweep 741 (19 May 1787), a region 5° northeast of M 80 brought 20 new vacant places.

It is remarkable that Herschel did not perceive the reflection nebula around ρ Oph (IC 4604) and another one around a fainter star 1° south (IC 4603); see Figure 4-24. The American astronomer Edward E. Barnard wrote in 1927:[980] “One very striking thing about all the nebulosity in this region is the fact that it is so faint that it cannot be seen with the eye even in a powerful telescope.” This is irritating because he had discovered them about 1882 with the 5-inch Byrne refractor at Nashville (Figure 4-24). He wrote that the region appeared “as if the sky were covered with a thin veiling of dust, that took away the rich background peculiar to many vacant regions of the heavens”.[981] The ρ Oph region was again observed in 1892 at the Lick Observatory with 6.5- and 12-inch refractors. Barnard always saw a combination of nebulae and vacant regions. There are several reasons why Herschel missed the IC objects. First, according to the sweep data, IC 4603 was not on his path. But what about the ρ Ophiuchi Nebula IC 4604? Its size exceeded the 15' field of view of the 20-ft, thus there was little contrast. Moreover, there was stray light by the 5th mag star. Another factor is the latitude difference between the observing sites: at Nashville, IC 4604 stands 30° above the horizon, about 16° higher than at Datchet. Finally, the reflection nebula is a much easier target for a small telescope, like Barnard’s 5-inch refractor, offering a wide field at a low magnification which give the necessary contrast. However, Herschel had the same chance with his 6.2-inch reflector: the double star ρ Oph was observed nine times (1780–83, 1804), but no nebula was seen!

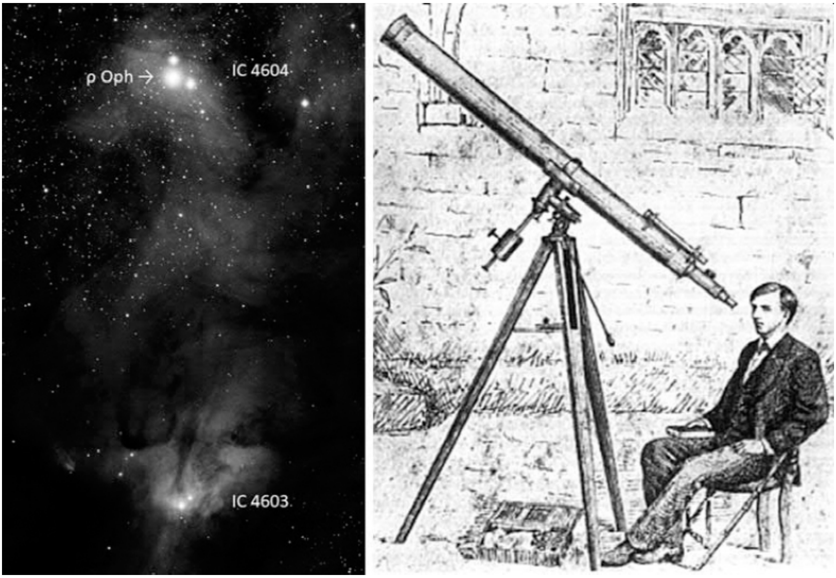


Figure 4-24: The large complex of reflection and dark nebulae in south-western Ophiuchus. The faint reflection nebulae IC 4603/04 (distance 1°) were found by Edward E. Barnard about 1882 with his 5-inch Byrne refractor at Nashville (right); the northern is illuminated by the 5th mag star ρ Oph.

In 1833 the story of the ‘hole in Scorpius’ was continued by Caroline, now living in Hanover. On 1 August she sent a letter to Mary (Lady Herschel) at Slough. At that time, 41-year-old John was preparing his Cape expedition to survey the southern sky (it started in November).982 In a postscript, addressed to him, Caroline wrote:983

Dear Nephew, as soon as your instrument is erected I wish you would see if there is not something remarkable in the lower part of the Scorpion to be found, for I remember your father returned several nights and years to the same spot, but could not satisfy himself about the uncommon appearance of that part of the heavens. It was something more than a total absence of stars (I believe). But you will have seen by the register, that those parts could only be marked *half swept*. I wish you health and good success to all you undertake and a happy return to a peaceful home in old England. God bless you all!

In a suitable moment, beside sweeping, John quickly observed the region, replying on 6 June 1834:[984] “I have not been unmindful of your hint about Scorpio. I am now *rummaging* the recesses of that constellation and find it full of beautiful globular clusters.” Caroline, not satisfied with John’s report, wrote back on 11 September:

I thank you for the promise of future accounts of uncommon objects. It is not Clusters of Stars I want you to discover in the Scorpion (or thereabout), for that does not answer my expectation, remembering having once heard your father, after a long, awful silence, exclaim: ‘Hier ist wahrhaftig ein Loch im Himmel!’ [here truly is a hole in the sky], and, as I said before, stopping afterwards at the same spot but leaving it unsatisfied, &c.[985]

It is remarkable that Caroline, at the age of 84, remembers this case so well after 50 years. Forced by his insisting aunt, John carefully checked his notes. The result was positive. Some observations, made on 29 July 1834 in sweep 474, matched Caroline’s query. On 22 February 1835, he wrote back. The letter lists ‘blank spaces’ (vacant fields) with positions for 1830: [986]

I have swept well over Scorpio and have entries in my sweeping books of the kind you describe – viz: blank spaces in the heavens without the smallest star. For example

AR 16^h 15^m NPD 113° 56' – a field without the smallest star

RA 16^h 19^m NPD 116° 3' – Antares (α Scorpii)

RA 16^h 23^m NPD 114° 25' to 114° 5' – field entirely void of stars

RA 16^h 26^m NPD 114° 15' – not a star 16 m. – Nothing!

RA 16^h 27^m NPD 114° 0' – not a star as far as 114° 10'

and so on – then come on the Globular Clusters – then more blank fields – then suddenly the Milky Way comes on as there described (from my Sweep 474. July 29. 1834).

Obviously, Caroline was pleased with the information given by John and their correspondence about the issue ended. But now the

astronomical community took over. Place and identity of the ‘hole in Scorpius’ was controversially discussed over many years. However, most ‘experts’ had never seen the original documents (sweep records, letters).

For instance, Johann Georg Hagen (see Figure 6-16) claimed that the ‘hole’ is the conspicuous dark nebula B 86 near the globular cluster NGC 6520 in Sagittarius (see Figure 4-23).[987] However, this object is 25° southeast of M 80! Although Herschel had discovered NGC 6520 in sweep 224 on 24 May 1784 (three days after finding the ‘hole’), he never saw the dark spot 9' northwest.

The Vatican astronomer was pointed to the case by the eminent science journalist Agnes Mary Clerke, who made a considerable remark in her book about the Herschels.[988] She wrote that William

> adverted to a black opening, four degrees wide, in the Zodiacal Scorpion, bordered on the west by an exceedingly compact cluster (Messier’s No. 80), possibly formed, he thought, of stars drawn from the adjacent vacancy. The chasm was to him one of the most impressive celestial phenomena. His sister preserved an indelible recollection of hearing him, in the course of his observations, after a long awful silence, exclaim, “Hier ist wahrhaftig ein Loch im Himmel!”; and he recurred to its examination night after night, and year after year, without ever clearing up, to his complete satisfaction, the mystery of its origin.

Triggered by these words, the Vatican astronomer searched for the source, which was not given by Clerke. With the aid of William Alfred Parr, a friend of the Herschel family at Slough, he eventually received a copy of Caroline’s letter of 11 September 1834.[989] In his paper, Hagen quotes the relevant part (he was not aware of the earlier correspondence).[990] Concerning size and position of the object, as given by Clerke (four degrees wide, east of M 80), he wrote: “In saying this, however, she appears to be merely stating her own conviction, as no source is quoted.” As was to be expected, the entire discussion brought no satisfactory result.

In his paper of 1785, Herschel mentions a second ‘hole’, about 4° south of the one in Scorpius:[991] “the fourth cluster of stars of the *Connaissance des Temps* [M 4]; which is also on the western border

of another vacancy, and has moreover a small, miniature cluster, or easily resolvable nebula of about 2½ minutes in diameter, north following it, at not very great distance [NGC 6144].” The observation was made in sweep 223 (22 May 1784). North of the bright globular cluster M 4 (located 1.3' west of Antares) the 10-field-counts dropped down to low values (1.6, 2.0). Herschel returned to the region of the ‘hole’ near M 80 on 26 May 1786 (sweep 566); seven vacant places were found.992 Later, in sweep 741 (19 May 1787), a region 5° northeast of M 80 brought 20 more.

Sw	Date	GMT	Start	End	D (')	Objects
212	11 May 1784	00:30 am – 01:05 am	15 46 -21 30	16 21 -23 21	2.0	M 80
215*	14 May 1784	00:20 am – 01:00 am	15 53 -23 42	16 32 -25 28	2.0	ρ Oph
222*	21 May 1784	09:15 pm – 01:45 am	13 17 -23 21	17 47 -24 32	2.0	M 80, ‘hole in Scorpius’
223*	22 May 1784	09:55 pm – 02:10 am	14 03 -24 56	18 15 -26 10	2.1	M 4 & NGC 6144, 2nd hole
224*	24 May 1784	10:35 pm – 02:00 am	14 54 -27 00	18 16 -28 18	2.2	M 4, 2nd ‘hole’
566	26 May 1786	10:50 pm – 02:00 am	15 11 -21 55	18 18 -23 44	2.6	M 80, ‘hole in Scorpius’
741	19 May 1787	10:30 pm – 00:50 am	14 24 -17 47	16 40 -19 59	2.2	north of M 80

Table 4-4: Sweeps covering the regions of M 80 and M 4 (* = ‘half swept’); positions for 2000; D = breadth.

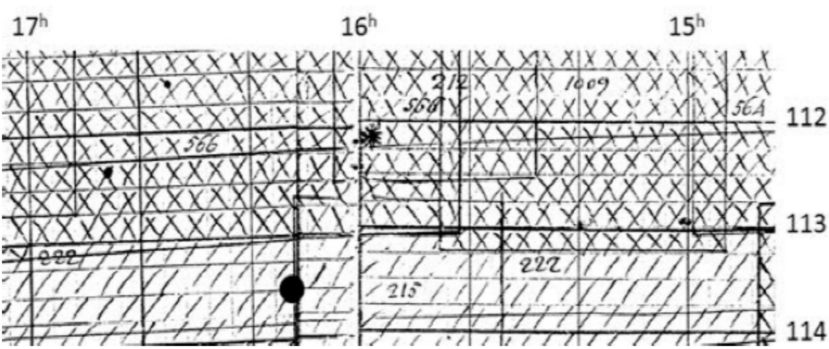
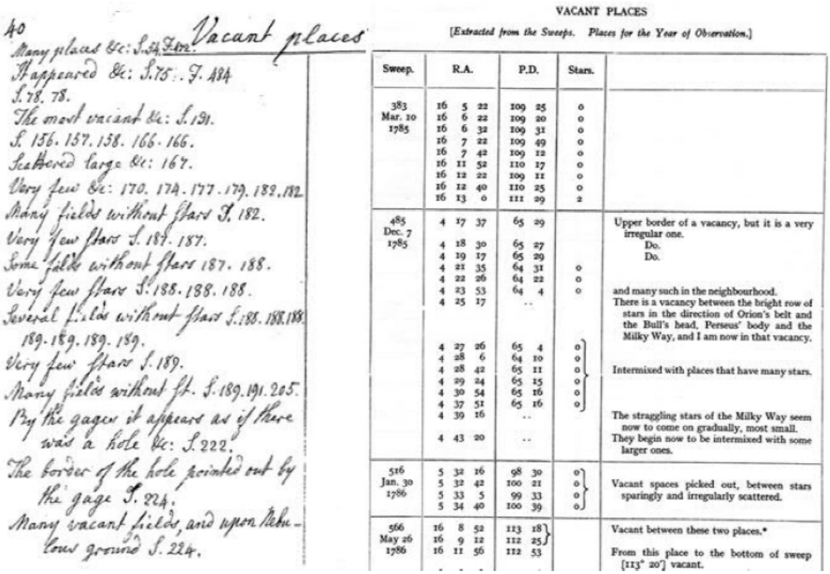


Figure 4-25: Part of the ‘Register of Sweeps’, showing sweeps 212, 215, 222 and 566, including the ‘hole in Scorpius’ (black spot by the author); Caroline’s ‘star’ marks M 80.993

Considering the recorded data, Caroline’s remark, “I remember your father returned several nights and years to the same spot”, in her first letter to John sounds curious. There is no evidence for more than two observations of the ‘hole in Scorpius’, either in the sweep records or in any other document (see Table 4-4). The position of the ‘hole’ is neither marked in Caroline’s ‘Register of Sweeps’ nor in the ‘Register of Gages’ (Figure 4-25).

Caroline lists 53 ‘vacant places’ in her ‘Temporary Index’. There is another list of 77 places, compiled on 10 April 1812 (taken from the sweep records with positions for 1690).[994] Later, Dreyer checked the sweep records, starting at sweep 383. He collected 77 cases in the *Scientific Papers* (Figure 4-26).[995]



40

Vacant places

Many places &c: S.54. F.102.
It appeared &c: S.75. F. 484
S.78. 78.
The most vacant &c: S.131.
S. 156. 157. 158. 166. 166.
Scattered large &c: 167.
Very few &c: 170. 174. 177. 179. 182. 182
Many fields without stars F. 182.
Very few stars S. 187. 187.
Some fields without stars 187. 188.
Very few stars S. 188. 188. 188.
Several fields without stars S. 188. 188. 188
189. 189. 189. 189.
Very few stars S. 189.
Many fields without st. S. 189. 191. 205.
By the gages it appears as if there was a hole &c: S. 222.
The border of the hole pointed out by the gage S. 224.
Many vacant fields, and upon Nebulous ground S. 224.

VACANT PLACES

[*Extracted from the Sweeps. Places for the Year of Observation.*]

Sweep.	R.A.	P.D.	Stars.	
383 Mar. 10 1785	16 5 22	109 25	0	
	16 6 22	109 20	0	
	16 6 32	109 31	0	
	16 7 22	109 49	0	
	16 7 42	109 12	0	
	16 11 52	110 17	0	
	16 12 22	109 11	0	
	16 12 40	110 25	0	
	16 13 0	111 29	2	
485 Dec. 7 1785	4 17 37	65 29		Upper border of a vacancy, but it is a very irregular one.
	4 18 30	65 27		Do.
	4 19 17	65 29		Do.
	4 21 35	64 31	0	
	4 22 26	64 22	0	
	4 23 53	64 4	0	and many such in the neighbourhood.
	4 25 17	..		There is a vacancy between the bright row of stars in the direction of Orion's belt and the Bull's head, Perseus' body and the Milky Way, and I am now in that vacancy.
	4 27 26	65 4	0	
	4 28 6	64 10	0	
	4 28 42	65 11	0	Intermixed with places that have many stars.
	4 29 24	65 15	0	
	4 30 54	65 16	0	
	4 37 51	65 16	0	
	4 39 16	..		The straggling stars of the Milky Way seem now to come on gradually, most small.
	4 43 20	..		They begin now to be intermixed with some larger ones.
516 Jan. 30 1786	5 32 16	98 30	0	Vacant spaces picked out, between stars sparingly and irregularly scattered.
	5 32 42	100 21	0	
	5 33 5	99 33	0	
	5 34 40	100 39	0	
566 May 26 1786	16 8 52	113 18		Vacant between these two places.*
	16 9 12	112 25		
	16 11 56	112 53		From this place to the bottom of sweep [113° 20'] vacant.

Figure 4-26: Lists of ‘vacant places’ by Caroline (left) and Dreyer.

A thorough investigation of the original documents yields: there are 199 vacant places, found in 77 sweeps. Following Caroline’s definition, this includes gages with a star number less than five. 98 lie in or near the band of the Milky Way (Figure 4-27).

We now know that ‘vacant places’ in the Milky Way are due to interstellar absorption by massive dust clouds – and not starless.[996] However, the vacant fields, located outside the Milky Way, are certainly real voids, at least regarding stars brighter than 14th magnitude. In some directions, e.g. towards the North Galactic Pole in Coma Berenices, there are only a few stars brighter than this limit. The Milky Way is pretty thin here. Of course, William Herschel could not distinguish between the two categories (dark nebula – void). Undoubtedly, the existence of ‘vacant places’ was an additional argument against a uniform scattering of stars.

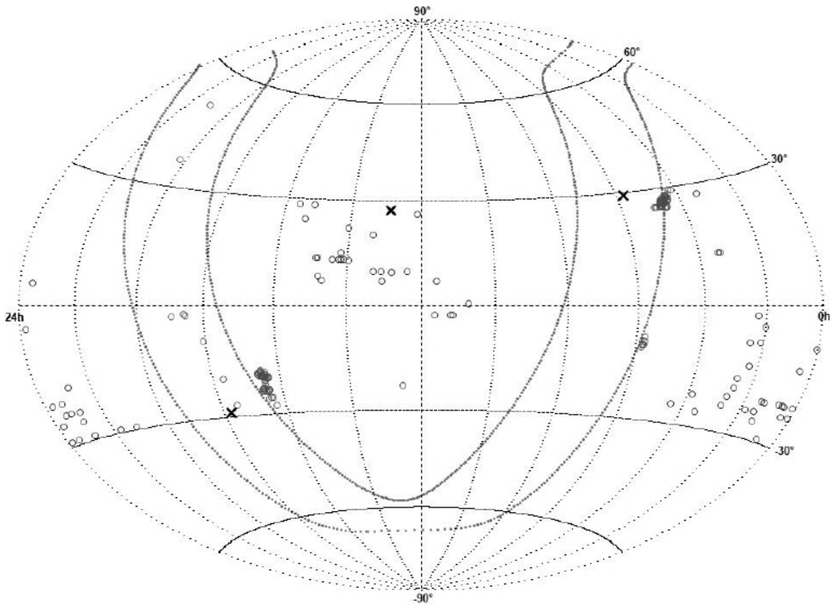


Figure 4-27: Distribution of all 'vacant places' on the sphere.

There is another interesting point concerning gages with low star numbers. Often, they were taken from 10 fields along the sweep path. This means that no nebula or cluster was seen (any discovery immediately would stop gaging). This remarkable coincidence was never discussed by Herschel. However, he treated the (rare) opposite case: a conjunction of cluster and void. The theoretical background is laid down in the paper of 1785. The section 'Formation of nebulae' defines the 'Form V' (see section 2.3.1):[997] "there will be formed great cavities or vacancies by the retreat of the stars towards the various centers which attract them; so that upon the whole there is evidently a field of the greatest variety for the mutual and combined attractions of heavenly bodies to exert themselves in." The main example is the 'hole in Scorpius', located near the globular cluster M 80. Herschel assumed that the gravitational forces of the massive cluster had attracted the stars in its neighbourhood, leaving an empty space: "the stars, of which it is composed, were collected from the place, and had left the vacancy". He may have thought about a 'circular hole' around the centre of gravity, but there were no observations proving it.

One may finally ask: Is it possible to identify the ‘vacant places’ in the Milky Way with known dark nebulae? The most important catalogues were published by Edward E. Barnard (B) in 1919/27 and Beverley Lynds (LDN) in 1962.[998] In 17 cases a Herschel region could be identified with a catalogue object (seven bear a B-number). Most successful were the sweeps 222–24 in May 1784, yielding seven known dark nebulae. Table 4-5 may be seen as the ‘Herschel catalogue of dark nebulae’.

Sweep	Date	Position	Con	Source	Dark nebula	Remarks
78	17 Jan.	04 08 +29 00	Tau	G	B 7	seen again in sweep 360
222	21 May	16 25 -23 48	Sco	G	B 42	hole in Scorpius near M 80, seen again in sweep 556
222	21 May	16 30 -23 46	Sco	G	LDN 457	
222	21 May	16 32 -23 46	Sco	G	LDN 462	
222	21 May	16 36 -23 46	Sco	G	B 44	
223	22 May	16 19 -25 44	Sco	G	B 229	near M 4, seen again in sweep 224
223	22 May	16 22 -25 43	Sco	G	LDN 441	near M 4
223	22 May	16 27 -25 44	Sco	G	LDN 453	near M 4 and NGC 6144
224	24 May	17 33 -25 42	Sco	G	B 78	
228	16 Jun.	18 01 -09 42	Sgr	V	LDN 400	near NGC 6517
242	21 Jul.	18 54 -03 08	Ser	G	LDN 535	
356	10 Oct.	05 44 -09 30	Ori	G	LDN 337	seen again in sweeps 362 and 516
383	10 Mar.	16 22 -20 23	Sco	V	B 41	
627	26 Oct.	04 24 +27 00	Tau	G	LDN 187	
627	26 Oct.	04 33 +26 00	Tau	V	LDN 214/29	
627	26 Oct.	04 33 +26 15	Tau	V	B 19	
862	26 Sep.	21 00 +51 11	Cyg	V	LDN 989	

Table 4-5: A ‘Herschel catalogue of dark nebulae’. It contains 17 vacant places, located in the or near the Milky Way, which can be identified with objects, listed in the main catalogues of dark nebulae (B, LDN). The (rough) position is for 2000.0. The most prominent case is the ‘hole in Scorpius’ near M 80 and ρ Oph, identified with B 42. Source: G = data are based on a star gage, V = Herschel only notes a ‘vacant place’.

4.1.6. John Herschel’s star counts and the fate of his father’s stratum

John Herschel never used his father’s ‘Fig. 4’ (Milky Way section) in any of his publications. Due to his own observations, made at Slough and the Cape, he agreed with William’s critical remarks about the conditions leading to the section (constant star density, uniformity, boundary). John even rejected the term ‘stratum of stars’. In 1835 he wrote that “the Milky Way is not a mere stratum, but an annulus; or at least, that our [solar] system is placed within one of the poorer and almost vacant parts of its general mass”.[999]

Nevertheless, in John Herschel's popular textbooks – *Treatise on Astronomy* (1833) and *Outlines of Astronomy* (1849) – we find a figure, showing a bifurcated stratum of stars and clusters (Figure 4-28).[1000] It was copied in the literature, for instance by Hind.[1001] For John, the famous nebula M 51 in Canes Venatici was a model of the Milky Way.[1002] This looks very similar to William's figure, showing the divided band of the Milky Way (Figure 4-15). On 26 April 1830 John had made a drawing, showing a bifurcated ring.[1003] However, the central condensation of M 51 appears more like a globular cluster, resembling the bulge of the Milky Way.[1004]

John had made no star counts at Slough. While observing his father's objects from 1825 to 1832 in 428 sweeps, he had no time for counting. There were only a few remarks about unusual star densities. Parallel to the compilation of the *Slough Catalogue*, he worked on his first book *Treatise on Astronomy*; the latter contains a first analysis of his observations (both works were published in 1833). The lack of star counts has been fixed at the Cape. There John performed systematic 'star gauges' in the southern sky (now using the correct word). As with William, they were by-products of the 382 sweeps. 268 of them contain star counts, starting in sweep 516 (1 December 1834) and ending in sweep 783 (1 April 1837). In total, there are 2600 gauges.

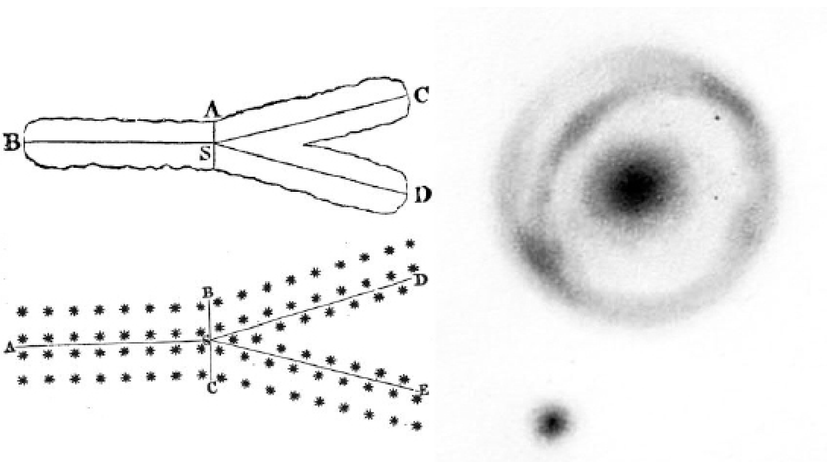


Figure 4-28: Left: John Herschel's Milky Way as bifurcated stratum (top). In 1853, John Hind published another version (below). Right:

M 51 in Canes Venatici was seen by John Herschel as a ‘ring nebula’ with a globular centre – a model of the Milky Way.

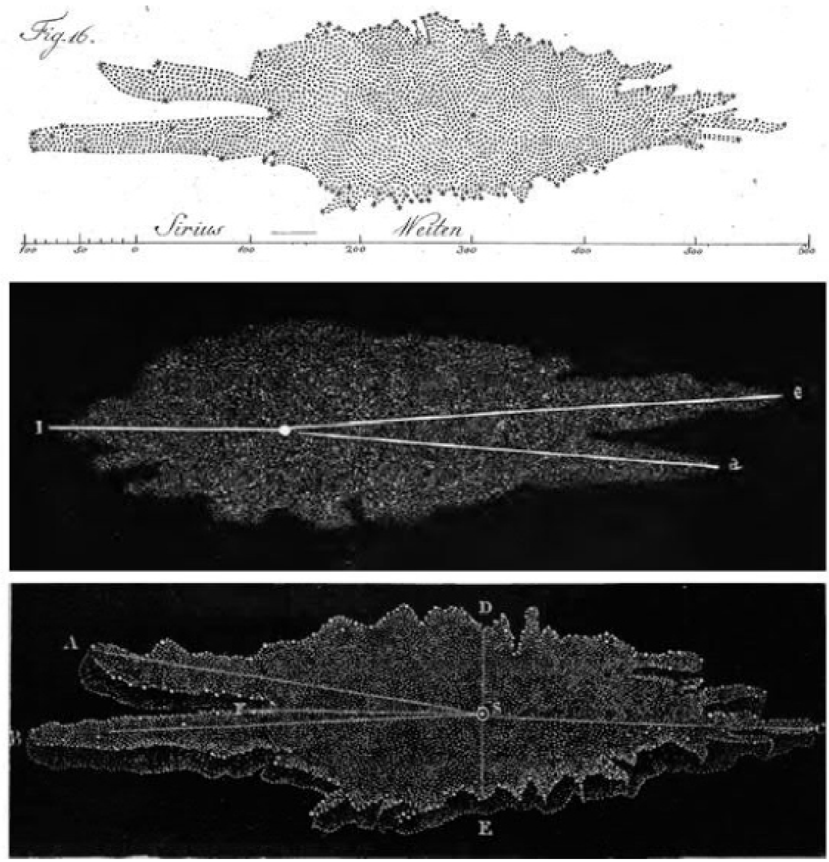


Figure 4-29: Top: German version William Herschel’s figure.1005 The scale is in units of the Sirius distance (‘Sirius-Weiten’); the horizontal extent is 600 (the ‘0’ point at left is strange). Middle: Mitchel’s ‘reversed’ version of 1851.1006 Bottom: Chambers’ ‘thick’ version of 1890.1007

The results of John’s Cape observations were published in 1847. Chapter IV is headed ‘Of the distribution of stars and of the constitution of the Galaxy in the southern hemisphere’. It contains a ‘Synoptic Table of Southern Star-Gauges’.1008 He arranged 68,948 stars (from 2299 fields) in galactic coordinates, quantifying the expected concentration towards the band of the Milky Way.

Moreover, he separated the stars by magnitude. A special focus was on vacant places; the Cape observations include a list of 49 areas.[1009] John concluded from his star counts that the brighter (nearer) stars show a uniform distribution, while the fainter (distant) stars are strongly concentrated towards the Milky Way. Moreover, the region about the Sun was found to be almost vacant, clearly separated from the Milky Way. For him, our stellar system was much more complex than a mere bifurcated 'stratum of stars', discussed by his father.[1010]

However, the new ideas did not diminish the popularity of William's section of the Milky Way. His famous 'Fig. 4' appeared in various versions in later publications (Figure 4-29). But sometimes it was incorrectly interpreted; either as a plane view of the Milky Way or as a derivative of his 1784 representation.[1011] The section is an independent view and does not replace the figure of 1784. Often the crucial word 'section' is missing in the literature. In some modern textbooks, Herschel's figure is compared with later (plane) views of the Milky Way by Jacobus Kapteyn, Harlow Shapley or John Plaskett, demonstrating the increasing knowledge about its size (larger stellar system) and the position of the Sun (away from the centre).[1012]

4.2. Herschel's interpretation of the observational data

4.2.1. The paper of 1811: sketches and 52 regions of 'extensive diffused nebulosity'

In 1811 and 1814, two papers were published, giving the 'big picture' – an evaluation of the observational results, concerning nebulae and star clusters. In the three catalogues, Herschel had put the discovered objects in a simple scheme of eight classes (I–VIII), based on their visual appearance (brightness, size, shape, concentration). But his idea, based on observational evidence, that true nebulous matter exists, required a more detailed approach. Already in the introduction of the third catalogue, he had given an 'evolutionary' view. Following this way, a new classification scheme was developed. This finally would lead to a morphological

sequence, to explain the physical nature of nebulae and star clusters, and their formation and evolution according to Newton's principles.

This should be achieved in two steps. First, William treated nebulae, sorted by Caroline into different categories in 1810/11. The manuscript was finished on 26 May 1811 and read to the *Royal Society* on 20 June. It was published as 'Astronomical Observations relating to the Construction of the Heavens, arranged for the Purpose of a critical Examination, the Result of which appears to throw some new Light upon the Organization of the celestial Bodies' in the *Philosophical Transactions* of 1811.[1013] In the introduction, Herschel summarizes his intention:

A KNOWLEDGE of the Construction of the heavens has always been the ultimate object of my observations, and having been many years engaged in applying my forty, twenty, and large ten feet telescopes, on account of their great space-penetrating power to review the most interesting objects discovered in my sweeps, as well as those which had before been communicated to the public in the Connoissance des Temps, for 1784, I find that by arranging these objects in a certain successive regular order, they may be viewed in a new light, and, if I am not mistaken, an examination of them will lead to consequences which cannot be indifferent to an inquiring mind.

If it should be remarked that in this new arrangement I am not entirely consistent with what I have already in former papers said on the nature of some objects that have come under my observation, I must freely confess that by continuing my sweeps of the heavens my opinion of the arrangement of the stars and their magnitudes, and of some other particulars, has undergone a gradual change; and indeed when the novelty of the subject is considered, we cannot be surprised that many things formerly taken for granted, should on examination prove to be different from what they were generally, but incautiously, supposed to be.

The nebulae are sorted into 34 'articles', often split into sub-articles (here using a, b, c …). They follow a sequence, defined by size and concentration, ranging from extensive diffused nebulosities to stellar nebulae. The former were large objects of extremely low

surface brightness, the latter point-like structures, but still different from stars. Table 4-6 shows all 'articles'.

No.	Article /sub-article		Ex.	Fig.
1	Extensive diffused Nebulosity		1	1
2	Extensive diffused Nebulosity (unpublished)		52	
3	Nebulosities joined to Nebulae		14	1
4	Detached Nebulosities		6	1
5	Milky Nebulae		7	-
6	Milky Nebulae with Condensation		4	1
7	Nebulae which are brighter in more than one Place		6	1
8	Double Nebulae with joined Nebulosity		15	1
9	Double Nebulae that are not more than two Minutes from each other		23	-
10	Double Nebulae at a greater Distance than 2' from each other		101	-
11a	'Multiple' Nebulae:	treble	20	-
11b		quadruple	5	
11c		sextuple	1	
12a	Nebulae:	(normal)	61	-
12b		extremely small	10	
12c		very small	136	
12d		not very small	42	
12e		small	107	
12f		pretty large	58	
12g		large	10	
13	Very narrow long Nebulae		5	1
14a	Extended Nebulae:	various small sizes	161	
14b		various large sizes	62	
14c		from ¾' to 2' long	31	
14d		from 2' to 5' long	24	
14e		from 5' to 15' long	6	
15a	Nebulae that are of an irregular Figure:	various small sizes	61	1
15b		various large sizes	32	
16a	Nebulae that are of an irregular round Figure:	various small sizes	28	1
16b		various large sizes	21	
16c		mean diameter 1' to 5'	6	
17a	Round Nebulae:	(general)	3	1
17b		various small sizes	41	
17c		various large sizes	10	
17d		from 1' to 6' in diameter	3	
18a	Nebulae that are remarkable for some particularity in Figure and Brightness:	figure	2	1
18b		unequally bright	10	
18c		brightest on one side	23	
19a	Nebulae which are gradually a little brighter in the middle:	unacertained figure	39	3
19b		extended	24	
19c		irregular figure	20	
19d		round, or nearly round	74	
20a	Nebulae which are gradually brighter in the middle:	unacertained figure	39	3
20b		extended	50	
20c		irregular figure	29	
20d		round, or nearly round	100	
21a	Nebulae which are gradually much brighter in the middle	unacertained figure	25	3
21b		extended	54	
21c		irregular figure	19	
21d		round, or nearly round	104	
22	Nebulae that have a Cometic appearance		17	1

No.	Article /sub-article		Ex.	Fig.
23a	Nebulae which are suddenly much brighter in the middle	unacertained figure	1	3
23b		extended	7	
23c		irregular figure	2	
23d		round, or nearly round	8	
24	Round Nebulae increasing gradually in brightness up to a Nucleus in the middle		13	1
25a	Nebulae that have a Nucleus:	extended	27	2
25b		round, or nearly round	13	
26a	Extended Nebulae that shew the Progress of Condensation:	nucleus and two opposite faint branches	23	2
26b		nucleus, chevelure and branches	5	
27a	Round Nebulae that shew the Progress of Condensation:	nucleus and faint chevelure	15	2
27b		two nebulae with a nucleus and chevelure resembling nebulous stars	2	
28a	Round Nebulae that are of an almost uniform light:	from 2' to 4' diameter	4	1
28b		from ¾' to 2' diameter	12	
29a	Nebulae that draw progressively towards a Period of final Condensation:	planetary appearance	4	2
29b		planetary disks with a bright central point	3	
30	Planetary Nebulae		10	1
31	Distance of the Nebula in the Constellation of Orion		1	2
32a	Stellar Nebulae:	brightest	6	2
32b		next degree of brightness	11	
32c		several degrees of faintness	100	
33a	Stellar Nebulae nearly approaching to the Appearance of Stars:	with burs	3	-
33b		with a faint chevelure	3	
34a	Doubtful Nebulae:	verified stellar nebulae	25	1
34b		verified with difficulty	5	
34c		not verified	4	

Table 4-6: Herschel's 'articles', describing various forms of nebulae, discussed in his 1811 paper; column 'Ex.' gives the number of examples, taken from the catalogues; 'Fig.' refers to the figured objects (see Table 4-8).

However, it is impossible to present each of the numerous examples, given in the paper. They cover a large fraction of all catalogued nebulae (1969 of 2303). One object appears in three articles: IV 94 = NGC 4343, a 12.1 mag galaxy in Virgo, found on 13 February 1784 (sweep 191). As member of a galaxy trio (with IV 95/96 = NGC 4341/42), it is in article 11a and as small, round nebula in 15b. Finally, the nebula was seen alone in sweep 498 on 28 December 1785 and described as 'little brighter in the middle', which qualified it for article 19b. There are 54 objects, presented in two articles. However, we will treat here only the figured nebulae (Table 4-8).

All objects were taken from the Herschel catalogues, except 25 of Messier's and the 52 regions of article 1 ('extensive diffused nebulosity'). The regions were seen in the sweeps, but not catalogued. We read about them:

The first article of my series will begin with extensive diffused nebulosity, which is a phenomenon that hitherto has not been much noticed, and can indeed only be perceived by instruments that collect a great quantity of light. Its existence, when some part of it

is pointed out by objects that are within the reach of common telescopes, has nevertheless obtruded itself already on the knowledge of astronomers, as will be seen in my third article … It may be easily supposed that in my sweeps of the heavens I was not inattentive to extensive diffusions of nebulosity, which occasionally fell under my observation. They can only be seen when the air is perfectly clear, and when the observer has been in the dark long enough for the eye to recover from the impression of having been in the light.

Herschel starts with a well-known case: V 14 (NGC 6992), the eastern part of the Veil Nebula in Cygnus. It was discovered on 6 September 1784 in sweep 258 and seen again on the 15th in sweep 272. The object is the first of 42, figured in two tables, appended to the paper. However, the western part, V 15 (NGC 6960) around 52 Cyg, and of a similar appearance, is not mentioned. He wrote:

The widely diffused nebulosity under consideration has been partially mentioned in my catalogues. The description of the object I shall select is of No. 14 in the 5th class [must read V 15], and is as follows: "Extremely faint branching nebulosity; its whitishness is entirely of the milky kind, and it is brighter in three or four places than in the rest; the stars of the milky way are scattered over it in the same manner as over the rest of the heavens. Its extent in the parallel is nearly 1½ degree, and in the meridional direction about 52 minutes. The following part of it is divided into several streams and windings, which after separating, meet each other again towards the south." See figure I [Plate II.].

This account, which agrees with what will be found in all the other numbers referred to, with regard to the subject under consideration, namely, a diffused milky nebulosity, will give us already some idea of its great abundance in the heavens; my next article however will far extend our conception of its quantity.

In a footnote, Herschel gives a few examples of "widely diffused nebulosity … mentioned in my catalogues". Ten class V objects ('large nebulae') are mentioned: V 13, 14, 15, 17, 28, 30, 31, 33, 34, 37, 38.[1014] The next section 'Observations of Nebulosities that have not been published before' lists 52 uncatalogued cases of 'extensive diffused nebulosity'. This is an obscure sample,

controversially discussed by later astronomers, like Barnard, Roberts or Hagen.[1015] Table 4-7 presents the 52 regions, sorted (as in the original) by right ascension for 1800.

Region	AR	PD	Size (°)	Con	NS	Sw	Object	Remarks
1	00 05 02	81 07	3.3	Psc	1	52		
2	00 12 31	86 34	7.7	Psc	2	338		
3	00 17 17	61 24	1.8	And	1	266		
4	00 20 31	86 34	3.6	Psc	1	338		
5	00 25 05	67 08	1.2	And	2	328		
6	00 31 22	90 04	5.7	Cet	3	988		
7	00 32 54	49 23	4.7	And	1	618	in M 31	
8	00 34 21	51 17	3.6	And	1	618		1.5° SW of M 31
9	00 36 13	47 03	8.6	And	1	621		3° N of M 31
10	00 43 32	46 58	1.4	And	1	621		
11	01 35 32	60 42	1.3	Tri	2	680		2.8° E of M 33 (V 17)
12	02 22 19	71 27	1.2	Ari	2	481		
13	03 56 14	65 06	1.7	Tau	1	485		40' S of IC 360
14	04 17 21	55 07	2.8	Per	1	1057		NGC 1579
15	04 18 21	550 6	5.0	Per	1	1057		15' NE of NGC 1579
16	04 21 35	97 44	1.1	Eri	2	782		
17	04 23 14	69 23	1.3	Tau	1	329		
18	04 38 17	69 23	1.3	Tau	1	329		
19	04 46 17	63 25	4.4	Tau	1	627		
20	05 09 06	65 06	3.4	Tau	1	485		
21	05 13 14	65 06	1.7	Tau	1	485		
22	05 23 59	97 01	6.3	Ori	4	529		2.1° NE of IC 430; D: NGC 1980 (V 31)
23	05 25 16	92 48	1.3	Ori	2	518		sw 352; Dreyer: NGC 1990 (V 34), 3° N
24	05 27 02	94 23	4.6	Ori	1	510		0.75° NE of NGC 1977 (V 30)
25	05 30 40	92 35	7.0	Ori	1	518	IC 434	
26	05 31 58	97 01	4.9	Ori	4	529		42' NE of IC 430
27	05 38 05	88 55	2.9	Ori	4	526	Barnard's Loop	
28	05 55 55	86 17	1.3	Ori	2	337		
29	05 56 36	110 28	5.0	Lep	1	304		
30	06 33 07	48 39	1.3	Aur	1	813		
31	09 22 56	108 03	1.2	Hya	1	368		
32	09 27 19	18 21	1.6	Uma	1	1112		1.4° NW of M 82
33	10 06 56	98 33	9.1	Sex	2	1035		
34	10 16 01	37 58	1.7	Uma	1	?		no sweep identified
35	10 34 29	26 44	1.6	Uma	1	1102		
Region	AR	PD	Size (°)	Con	NS	Sw	Object	Remarks
36	10 58 24	26 44	2.3	Uma	1	1102		
37	11 56 59	58 50	2.0	Uma	1	805		
38	12 07 34	58 50	2.0	Com	2	805		
39	13 07 33	55 20	1.0	CVn	2	407		
40	13 58 00	55 20	1.6	CVn	1	406		
41	15 05 07	70 40	4.7	Ser	1	1006		
42	20 48 20	92 17	4.1	Aqr	3	1110		
43	20 48 50	73 38	1.4	Del	2	290		
44	20 51 04	46 51	2.8	Cyg	2	620	NGC 7000 (V 37)	sweep 959
45	20 52 28	91 57	0.8	Aqr	2	1110		
46	20 53 31	47 07	3.7	Cyg	2	620	NGC 7000 (V 37)	sweep 959
47	21 00 26	76 03	2.0	Peg	1	294		
48	21 29 27	80 08	1.1	Peg	1	419		
49	21 42 16	68 57	1.2	Peg	1	319		
50	22 52 36	64 47	1.3	Peg	2	327		
51	22 53 06	64 47	1.9	Peg	2	327		
52	22 55 29	61 15	1.2	Peg	1	267		

Table 4-7: Herschel's 52 regions of 'extensive diffused nebulosity'.

‘NS’ gives the number of sweeps, in which the region could be seen; ‘Sw’ is the sweep, in which the ‘object’ was perceived. ‘Object’ mentions a confirmed region. The last column mentions a large nebula in the vicinity, which is not counted as an identification here.

Figure 4-30: This bright part of Barnard’s Loop in Orion, seen on 22 February 1786 (sweep 526), matches region no. 27; the nebula

below is M 78.

Two regions can be identified with class V objects: no. 44 and 46 are parts of NGC 7000 (V 37), the North America Nebula in Cygnus (Figure 2-131). V 30 (NGC 1977) fits pretty well to no. 24. IC 434 (the emission part of the Horsehead Nebula) may be no. 25. Region no. 27 matches to the brightest part of Barnard's Loop in Orion (Figure 4-30); the large supernova remnant bears no NGC/IC number.[1016]

Herschel perceived these diffuse objects all over the sky, even at places far away from the Milky Way, where no large, diffuse nebulae exist. Anyway, while sweeping, he occasionally had the impression that the field is not as dark as usual, but filled with a 'whitish haziness'. He also used terms like 'affected with nebulosity', 'suspected faint nebulosity', 'faint milky nebulosity' or 'faint whitish nebulosity'. This impression appeared in certain fields on the sweep path, the full breadth or even larger parts of the sweep area. The estimated size ranged from 0.8° to 9.1°. Herschel wrote: "When this account says affected, it is intended to mean that the ground upon which, or through which we see, or may see stars, is affected with nebulosity." A critical question should be allowed: How could he perceive such extended objects with extremely low surface brightness, when the field of view was only 15′? The problem is the lack of contrast inside the region. A visual effect would only be noticeable at the 'border' where the brightness differs from the background. Anyway, this subject is mysterious.[1017]

Herschel presents sketches of 42 nebulae, collected on plates IV and V (Table 4-8 and Figure 4-31).[1018] The figures illustrate a certain article. Three Messier objects are shown: M 42, M 63 and M 65. For the Orion Nebula, Herschel compares his own sketch with that of Huygens.

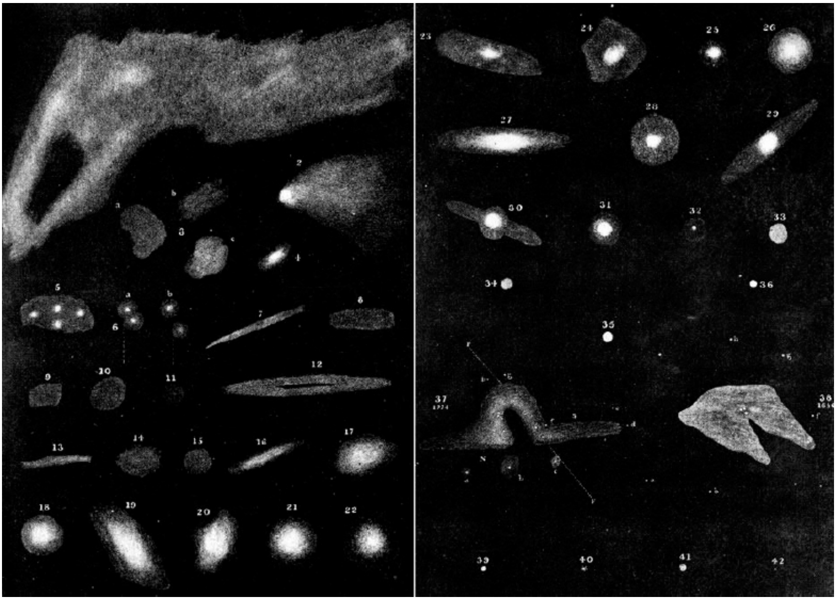


Figure 4-31: 42 nebulae, figured in the 1811 paper. The large object upper left is the eastern part of the Veil Nebula (V 14, NGC 6992), a region of ‘extensive diffused nebulosity’. On the right plate we see M 42, drawn by Herschel and Huygens.

Fig.	Art.	H/M	NGC	Con	Type	V	Sw	Date	Remarks	Image
1	1	V 14	6992	Cyg	EN	7.0	258	6 Sep. 1784	Veil Nebula (east)	Figure 2-70
2	3	I 214	5474	UMa	Gx	10.8	840	1 May 1788	asymmetric nucleus	Figure 2-164
3	4	V 21	2359	CMa	EN	11.5	363	31 Jan. 1785	three parts	Figure 2-82
4	6	I 11	4153	Com	GC	10.4	146	15 Feb. 1784	concentration class VI	Figure 2-39
5	7	I 213	4449	CVn	Gx	9.6	833	27 Apr. 1788	CH 8 July 1793, 4 knots	Figure 2-163
6	8	II 316/17	2371/72	Gem	PN	11.2	385	12 Mar. 1785	double nebula	Figure 2-83
7	13	III 254	3044	Sex	Gx	11.9	348	20 Dec. 1784	extremely flat	Figure 2-75
8	13	II 514	1620	Eri	Gx	12.3	506	1 Jan. 1786	elongated	
9	15	I 61	2974	Sex	Gx	10.9	353	6 Jan. 1785	star superimposed	
10	16	III 177	925	Tri	Gx	10.1	271	13 Sep. 1784		Figure 2-64
11	17	I 269	3488	UMa	Gx	12.9	1038	8 Apr. 1793	star near	
12	18	V 19	891	And	Gx	9.9	621	24 Oct. 1786	edge-on, dark lane	Figure 2-63
13	19	III 488	2848	Hya	Gx	11.8	503	31 Dec. 1785		
14	19	II 549	4818	Vir	Gx	11.1	536	3 Mar. 1786	elongated	
15	19	II 812	6338	Dra	Gx	12.3	928	24 Apr. 1789		
16	20	I 55	7479	Peg	Gx	10.9	476	23 Nov. 1785	bar, face-on	Figure 2-72
17	20	I 266	3206	UMa	Gx	11.9	1038	8 Apr. 1793		
18	20	I 98	5273	CVn	Gx	11.6	405	1 May 1785		
19	21	I 101	779	Cet	Gx	11.2	474	22 Nov. 1785	edge-on	Figure 2-175
20	21	I 219	3665	UMa	Gx	10.8	915	23 Mar. 1789		
21	21	I 63	1052	Cet	Gx	10.5	355	10 Jan. 1785		
22	22	I 4	3169	Sex	Gx	10.2	513	27 Jan. 1786		
23	23	I 39	4697	Vir	Gx	9.2	205	24 Apr. 1784		
24	23	I 256	5322	UMa	Gx	10.2	953	19 Mar. 1790		Figure 2-180
25	23	I 99	5557	Boo	Gx	11.0	738	16 May 1787		
26	24	I 151	524	Psc	Gx	10.2	581	4 Sep. 1786		
27	25	M 63	5055	CVn	Gx	8.6	717	18 Mar. 1787	Sunflower Galaxy	Figure 2-146
28	25	I 107	1407	Eri	Gx	9.7	459	6 Oct. 1785		Figure 2-102
29	26	M 65	3623	Leo	Gx	9.3	531	24 Feb. 1786	elongated	Figure 2-59
30	26	I 205	2841	UMa	Gx	9.2	815	9 Mar. 1788	elongated	Figure 2-162
31	27	IV 23	936	Cet	Gx	10.2	351	6 Jan. 1785	bar	
32	27	III 99	5210	Vir	Gx	12.9	1042	12 May 1793	compact	
33	28	IV 13	6894	Cyg	PN	12.3	259	7 Sep. 1784		
34	29	IV 55	2537	Lyn	Gx	11.7	817	10 Mar. 1788	Bear Paw Galaxy	Figure 2-160
35	29	IV 37	6543	Dra	PN	8.1	523	15 Feb. 1786	central star	Figure 2-117
36	30	IV 18	7662	And	PN	8.3	283	6 Oct. 1784	Blue Snowball	
37	31	M 42	1976	Ori	EN	4.0	-	11 Mar. 1811	Orion Nebula	Figure 1-4
38	31	M 42	1976	Ori	EN	4.0	-	1656	Orion Nebula (Huygens)	Figure 3-30
39	32	I 268	3458	UMa	Gx	12.3	1038	8 Apr. 1793		
40	32	II 110	4262	Com	Gx	11.6	691	14 Jan. 1787		
41	32	II 603	1275	Per	Gx	11.9	614	17 Oct. 1786		
42	34	III 7	2508	CMi	Gx	12.7	100	23 Jan. 1784	stellar	Figure 2-28

Table 4-8: The 42 figured objects of the 1811 paper. 'Sw' and 'Date' gives sweep/date where the description, reproduced in the text, was taken from. This can differ from the discovery date (see Figure 4-31).

4.2.2. The paper of 1814: nebulous stars, star clusters and more sketches

The second paper of the series was published in 1814: 'Astronomical Observations relating to the sidereal part of the Heavens, and its Connection with the nebulous part: arranged for the purpose of a critical Examination.' The manuscript was read to

the *Royal Society* on 24 February.[1019] As the title implies, the focus is now on stars associated with nebulae and star clusters in their various forms. The approach is similar to that of the former paper. Herschel wrote in the introduction:

In my paper of observations of the nebulous part of the heavens [PT 1811], I have endeavoured to shew the probability of a very gradual conversion of the nebulous matter into the sidereal appearance. The observations contained in this paper are intended to display the sidereal part of the heavens, and also to shew the intimate connection between the two opposite extremes, one of which is the immensity of the widely diffused and seemingly chaotic nebulous matter; and the other, the highly complicated and most artificially constructed globular clusters of compressed stars. The proof of an intimate connection between these extremes will greatly support the probability of the conversion of the one into the other; and in order to make this connection gradually visible, I have arranged my observations into a series of collections, such as I suppose will best answer the end of a critical examination.

No.	Article / sub-article		Ex.	Fig.
1	Stars in remarkable situations with regard to Nebulae		5	1
2	Two stars with nebulosity between them		19	2
3a	Stars with nebulosities of various shapes attached to them:	with brush	9	3
3b		with puff	2	
3c		with fan-shaped nebulosity	3	
4	Stars with nebulous branches		3	1
5	Nebulous Stars		13	1
6	Stars connected with extensive windings of nebulosity		3	1
7	Small patches consisting of Stars mixed with nebulosity		37	1
8a	Objects of an ambiguous construction:	first collection	7	2
8b		second collection	26	
8c		third collection	26	
8d		fourth collection	12	
9	Sidereal part of the Heavens		-	-
10a	Aggregation of Stars:	in the milky way	15	1
10b		near the milky way	5	
11a	Irregular Clusters:	various unascertained sizes, in the milky way	53	1
11b		various unascertained sizes, near the milky way	18	
11c		various unascertained sizes, at a distance from it	9	
11d		from 2' to 30' diameter, in the milky way	22	
11e		from 2' to 30' diameter, near the milky way	10	
12a	Clusters variously extended and compressed:	in the milky way	12	1
12b		near the milky way	3	
13a	Clusters of Stars of a peculiar description:	in the milky way	1	-
13b		near the milky way	3	
13c		at a distance from it	2	
14a	Differently compressed Clusters of Stars:	in the milky way	17	-
14b		near the milky way	15	
14c		at a distance from it	1	
14d		clusters of very compressed stars, in the milky way	5	
14e		clusters of very compressed stars, in the milky way	2	
14f		clusters of very compressed stars, at a distance from it	1	
15a	Gradual concentration and insulation of Stars:	in the milky way	21	1
15b		near the milky way	7	
15c		at a distance from it	11	
16a	Globular Clusters of Stars:	in the milky way	1	1
16b		near the milky way	4	
16c		at a distance from it	9	
17a	More distant globular Clusters of Stars:	in the milky way	5	-
17b		at a distance from it	5	
18	Still more distant globular Clusters of Stars		5	-
19	A recurrence of the ambiguous limit of observation		-	-
20	The breaking up of the milky way		-	-

Table 4-9: The articles of the 1814 paper. They concern stars with nebulosity and star clusters; ‘Ex.’ gives the number of examples, mentioned in the paper, and ‘Fig.’ refers to the figured objects (see Table 4-10).

In all, 361 objects are listed in 18 articles and their sub-articles (Table 4-9). Of these, 164 are in classes I-V (there is an overlap with the former paper); 197 are in classes VI–VIII (all objects of these classes are given).

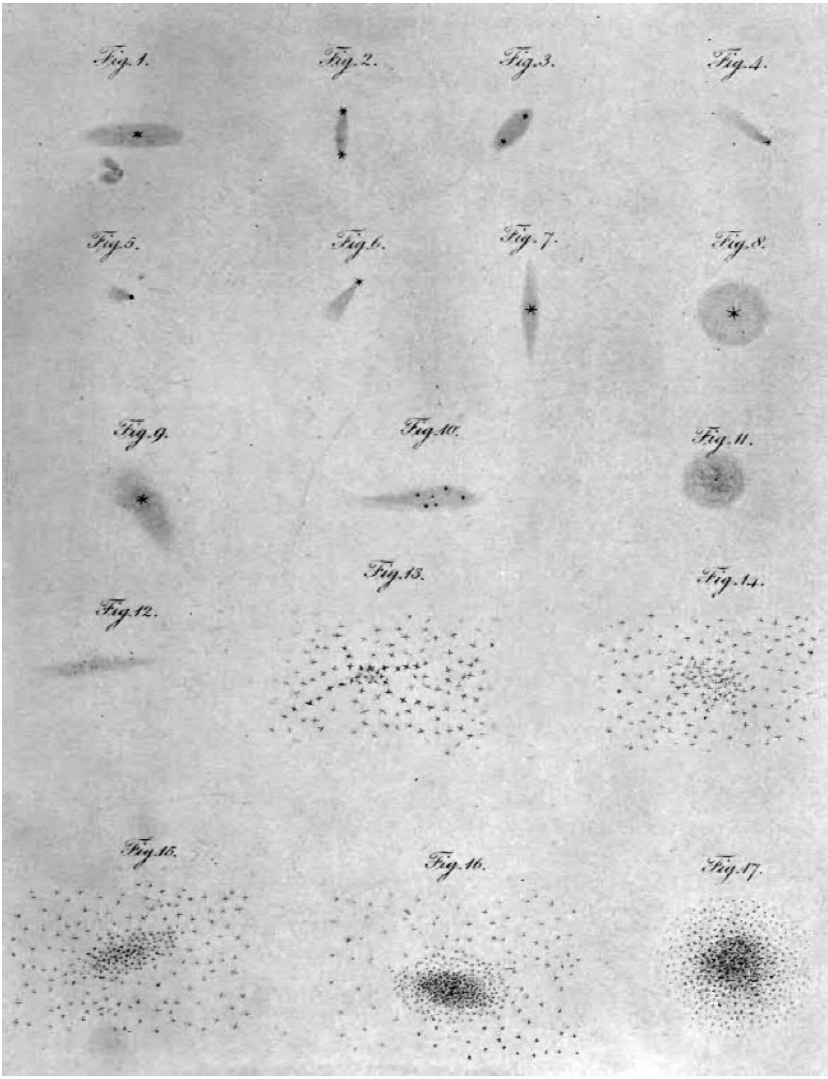


Figure 4-32: The 17 objects figured in 1814 publication on Plate IX (see Table 4-10).

One object is in two articles: VI 12 = NGC 6304, an 8.2 mag globular cluster in Ophiuchus (24 May 1784, sweep 224). It is in 14b ('differently compressed Clusters of Stars, near the milky way') and 17a ('more distant globular clusters of stars, in the milky way'). In the sweep record, the object is described as a miniature version of M 19. It is interesting that six objects in the 1814 table are

already in that of 1811. Two cases concern stellar nebulae (treated in both papers). Interesting is the 13th mag galaxy II 84 (NGC 4328) in Coma Berenices, 6' east of M 100; it is noted under article 10 in 1811 (‘double nebulae’) and 8 (‘ambiguous’) in 1814, together with M 100. Herschel wrote about the pair: “it is probable that that they belong to the order of clusters of stars”; especially for M 100, he guessed ”in the middle of it, a small cluster of supposed stars”. The 8.3 mag globular cluster NGC 6304 in Ophiuchus was classified as ‘bright nebula’ I 147 and 1811 put in article 21d (‘round or nearly round nebulae, gradually much brighter in the middle’). Class VI was not applied, though it was seen ‘resolvable’ in sweep 559 (30 April 1786) and appeared as a ‘miniature’ of the globular cluster M 62. In 1814, the object appears in article 18 (‘still more distant globular clusters of Stars’). It should be noted that 176 catalogue objects do not appear in any paper. Sketches of 17 objects are collected in a table (Table 4-10, Figure 4-32);[1020] 11 Herschel objects are in classes I-IV, five in VI–VIII. Two are mere star groups; one Messier object is shown (M 72).

Fig.	Art.	H/M	NGC	Con	Type	V	Sw	Date	Remarks	Image
1	1	V 46	3556	UMa	Gx	10.0	922	17 Apr. 1789	M 108, edge-on	
2	2	III 67	3473	Leo	Gx	13.5	181	21 Mar. 1784	pair with NGC 3474	Figure 2-51
3	2	II 706	7538	Cep	EN		773	3 Nov. 1787		Figure 2-156
4	3	I 143	4900	Vir	Gx	11.4	558	30 Apr. 1786	star near	Figure 2-92
5	3	IV 4	3662	Leo	Gx	12.9	153	22 Feb. 1784	star superimposed	Figure 2-40
6	3	IV 35	2610	Hya	PN	12.7	503	31 Dec. 1785	annular nebula	Figure 2-107
7	4	IV 42	676	Psc	Gx	11.9	607	30 Sep. 1786	edge-on, star superimposed	Figure 2-127
8	5	IV 69	1514	Tau	PN	10.9	980	13 Nov. 1790	central star	Figure 2-182
9	6	IV 33	1999	Ori	EN		529	24 Feb. 1786	‘central star’, dark structure	Figure 2-108
10	7	III 697	4183	CVn	Gx	12.3	798	14 Jan. 1788	extremely flat	Figure 2-158
11	8	III 101	5239	Boo	Gx	12.8	191	13 Apr. 1784	face-on	Figure 2-60
12	8	II 500	4535	Vir	Gx	10.0	498	28 Dec. 1785	face-on	Figure 2-106
13	10	VIII 44	2394	CMi			496	28 Dec. 1785	star group	Figure 2-106
14	11	VIII 4	1896	Aur			525	16 Feb. 1786	star group	
15	12	VI 36	2432	Pup	OC	10.2	934	4 Mar. 1790		Figure 2-9
16	15	VI 5	2194	Ori	OC	8.5	138	11 Feb. 1784		
17	16	M 72	6981	Aqr	GC	9.2	-	30 Oct. 1810	concentration class IX	Figure 2-78

Table 4-10: Figured objects in the paper of 1814. ‘Sw’ and ‘Date’ gives the sweep (and date) where the description, reproduced in the text, was taken from. This can differ from the discovery date (see Figure 4-32).

4.2.3. The papers of 1817 and 1818 – a matter of ‘profundity’

The ‘Astronomical observations’ series was completed with the

papers of 1817 and 1818. They concern the distances of stars and non-stellar objects, respectively. The manuscript of the first is dated 10 May 1817. It was read to the *Royal Society* on 19 June and published in the *Philosophical Transactions* for 1818 as 'Astronomical observations and experiments tending to investigate the local arrangement of the celestial bodies in space, and to determine the extent and condition of the Milky Way'.[1021] It is a continuation of the papers on the 'construction of the heavens', which concerned to the shape and extent of the Milky Way, based on 'star gages' (see section 4.1).

The last paper, 'Astronomical observations and experiments, selected for the purpose of ascertaining the relative distances of clusters of stars, and of investigating how far the power of our telescopes may be expected to reach into space, when directed to ambiguous celestial objects', enlarges the scope from stars to star clusters. For a sample of objects, their location in three-dimensional space is determined. The paper was read to the *Royal Society* on 11 June 1818 and published in the *Philosophical Transactions* of that year.[1022] The basic term is 'profundity', a distance measure. In the introduction of the 1817 paper, Herschel wrote:

The construction of the heavens, in which the real place of every celestial object in space is to be determined, can only be delineated with precision, when we have the situation of each heavenly body assigned in three dimensions, which in the case of the visible universe may be called length, breadth, and depth; or longitude, latitude, and Profundity.

The angular positions of the stars and other celestial objects, as they are given in astronomical catalogues, and represented upon globes, or laid down in maps, enable us, in a clear night, to find them by the eye or to view them in a telescope; for, in order to direct an instrument to them, a superficial place consisting of only two dimensions is sufficient; but although the line in which they are to be seen is thus pointed out to us, their distance from the eye in that line remains unknown; and unless a proper method for obtaining the profundity of objects can be found, their longitude and latitude will not enable us to assign their local arrangement in space.

Herschel develops such a 'proper method for obtaining the

profundity' on visual observations only. What was his approach and how reliable is the resulting 'profundity'? He knew that the distance of a cosmic object can be derived from trigonometric parallax, linear diameter or (absolute) brightness. Herschel wrote that for stars or clusters "the parallax method can give us no assistance" (it was too small to measure). Because there was no information about the real sizes of cosmic objects, he focused on brightness. Knowing that the number of stars increases with magnitude, he concluded: "since in our catalogues the magnitudes are added to the two dimensions which give the superficial place of the stars, we have also at least a presumptive value of the third dimension". However, a "certain standard of reference" was needed. Herschel was certain to have found one, which "does not require that the stars should be at equal distances from each other; nor is it necessary that all those of the same nominal magnitude should be equally distant from us". These are essential requirements. He described the method as follows:

It consists in allotting a certain equal portion of space to every star, in consequence of which we may calculate how many stars any given extent of space should contain. This definition of equal scattering agrees so far with observation, that it admits, for instance, Sirius, Arcturus, and Aldebaran to be put into the same class, notwithstanding their very different lustre will not allow us to suppose them to be at equal distances from us; but its chief advantage will be, that instead of the order of magnitudes into which our catalogues have arranged the stars, it will give us an order of distances, which may be used for ascertaining the local distribution of the heavenly bodies in space.

In the 1818 paper, Herschel applied his method to star clusters, writing in the introduction:

In my last paper on the local arrangement of the celestial bodies in space, I have shown how, by an equalization of the light of stars of different brightness, we may ascertain their relative distances from the observer, in the direction of the line in which they are seen; and from this equalization, a method of turning the space-penetrating power of a telescope into a gradually increasing series of gaging powers has been deduced, by which means the profundity in space,

of every object consisting of stars, can be ascertained, as far as the light of the instrument which is used upon this occasion will reach. This method has already been applied to fathom the milky way, and may with equal propriety be used to ascertain the profundity of globular and other clusters of stars in space; I shall therefore make use of some of the numerous observations, contained in my journals and sweeps of the heavens, to show how the distances of these objects may be obtained; and shall also attempt to represent their situation in space by a figure, in which their distances are made proportional to the diameter of a globular space, sufficiently large to contain all the stars that in the clearest nights are visible to the eye of an observer.

Herschel's sample consists of 58 objects (Table 4-11). 12 are from his catalogues (11 are in class VI and one in IV); 46 were taken from the *Messier Catalogue*. The sample is a mix of various types: 31 objects are globular clusters, seven are open clusters, five are galaxies, three are planetary nebulae and one is an emission nebula, the Crab Nebula M 1 in Taurus.

Object	Profundity	Dist. (kly)	Con	V	Type	Remarks
VI 7	734	53.5	Com	9.0	GC	NGC 5053
VI 9	734	51.9	Boo	9.2	GC	NGC 5466
VI 10	734	27.7	Sco	9.0	GC	NGC 6144
VI 11	734	49.9	Oph	8.9	GC	NGC 6284
VI 12	466	29.3	Oph	8.3	GC	NGC 6293
VI 17	600	16.2	Gem	8.6	OC	NGC 2158
VI 20	734	28.7	Scl	8.1	GC	NGC 288
VI 26	900	8.3	Per	10.7	OC	NGC 1605
VI 35	900	17	Cas	11.5	OC	NGC 136
VI 38	900	4.2	Aql	12.0	PN	NGC 6804
VI 41	900	67000	Dra	11.8	Gx	NGC 6412
IV 63	900	14000	UMa	11.3	Gx	NGC 5204
M 1	980	6.5	Tau	8.4	EN	Crab Nebula
M 2	243	33	Aqr	6.6	GC	
M 3	243	33.9	CVn	6.3	GC	
M 4	344	7.2	Sco	5.4	GC	
M 5	243	24.5	Ser	5.7	GC	
M 9	344	25.8	Oph	7.8	GC	
M 10	243	14.3	Oph	6.6	GC	
M 11	144	6.2	Sct	5.8	OC	Wild Duck Cluster
M 12	186	16	Oph	6.1	GC	
M 13	243	22.2	Her	5.8	GC	
M 14	900	30.3	Oph	7.6	GC	
M 15	243	33	Peg	6.3	GC	
M 19	344	28.7	Oph	6.8	GC	
M 22	344	10.6	Sgr	5.2	GC	
M 30	344	29.4	Cap	6.9	GC	
M 33	344	2725	Tri	5.7	Gx	Triangulum Nebula
M 34	144	1.5	Per	5.2	OC	
M 35	144	2.8	Gem	5.1	OC	
M 53	243	58	Com	7.7	GC	
M 55	400	17.6	Sgr	6.3	GC	
M 56	344	32.9	Lyr	8.4	GC	
M 57	950	2.7	Lyr	8.8	PN	Ring Nebula
M 62	734	22.2	Oph	6.4	GC	
M 67	144	2.77	CNC	6.9	OC	
M 68	344	33.6	Hya	7.3	GC	
M 69	734	29.7	Sgr	8.3	GC	
M 71	243	13	Sge	8.4	GC	
M 72	243	54.6	Aqr	9.2	GC	
M 74	243	30000	Psc	9.4	Gx	
M 75	734	67.5	Sgr	8.6	GC	
M 77	910	47000	Cet	8.9	Gx	
M 79	344	41	Lep	7.7	GC	
M 80	734	32.6	Sco	7.3	GC	
M 92	243	26.7	Her	6.5	GC	
M 97	980	2.03	UMa	9.9	PN	Owl Nebula

Table 4-11: The 56 non-stellar objects, treated in the 1818 paper. Herschel's distances ('profundity') by no means matches the true values ('Dist.' from Earth), even for a unique type; 1 kly = 1000

light-years.

The class IV object is interesting, the 11.3 mag galaxy NGC 5204 (IV 63) in Ursa Major (Figure 4-33). The modern classification is Sm (spiral galaxy of the 'magellanic' type). These objects resemble the appearance of the irregular, loose-structured Magellanic Clouds. In a telescope it visually looks somewhat 'mottled' (which does not mean 'resolved'). Herschel wrote on 24 April 1789 (sweep 926): "considerably bright, considerably large, very gradually much brighter middle, irregularly round, easily resolvable. I suppose with a higher power I might have seen stars, 4' diameter."

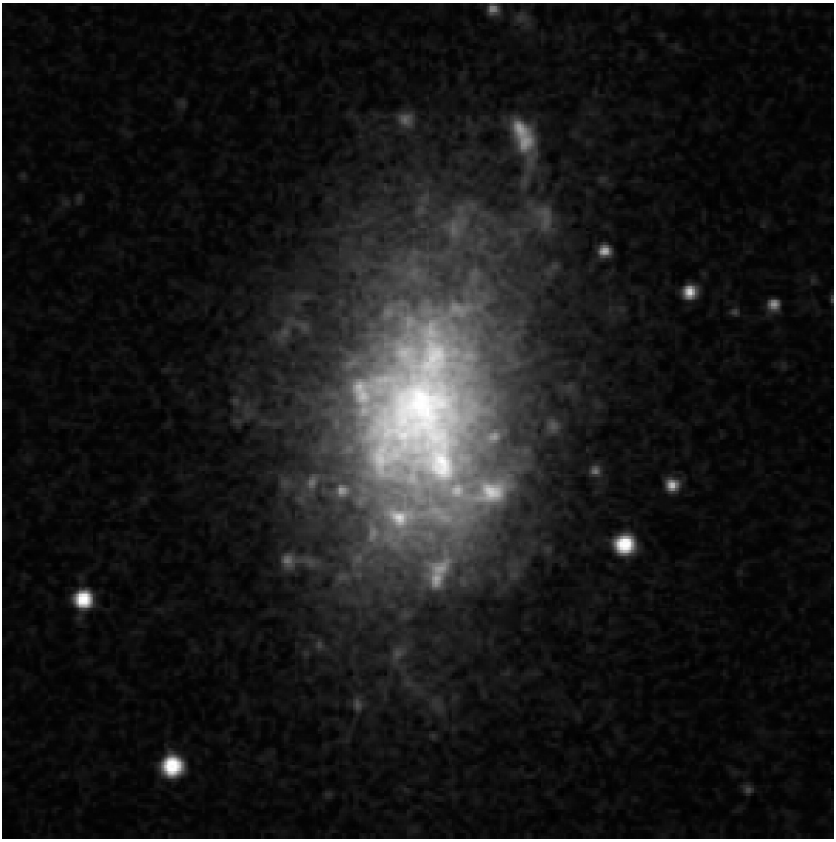


Figure 4-33: The 11.3 mag galaxy NGC 5204 (IV 63) in Ursa Major is of the 'magellanic' type. Herschel found the object on 24 April 1789.

Based on the ‘profundity’ method, yielding a certain ‘distance’, Herschel determined the 3-dimensional distribution of the objects, though presented in a two-dimensional projection (Figure 4-34).[1023] Of course, the actual special distribution, based on modern distance measures (the values are also listed in the table), looks very different.

This is not only due to presence of the three galaxies (M 77, NGC 5204, NGC 6412) in the sample. There is even no correlation for special object types, like globular clusters. Though William Herschel’s distance measure, determined by gaging and based on several theoretical assumptions, was fairly good for stars, it completely failed for non-stellar objects.

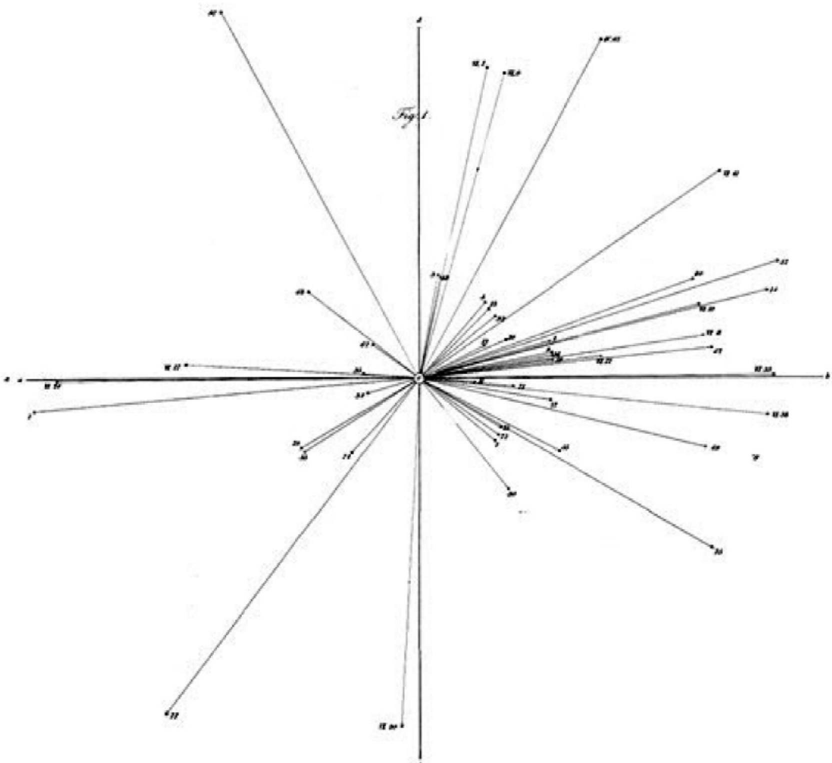


Figure 4-34: Herschel’s ‘profundity’ is a distance measure. He applied it for stars, but also for non-stellar objects, as shown here. His two-dimensional view (projection), shows all 58 cases, treated in his publication of 1818. However, it does not match true

distances – not even for a homogenous sample, like globular clusters.

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943 Herschel always used the incorrect word 'gage' instead of 'gauge'. Anyway, the former term is used here.
944 Steinicke (2017a).
945 RS MS/272.
946 Herschel W. (1784b). For a detailed study of Herschel's papers on the 'construction of the heavens', see Hoskin (2012a).
947 Ferguson (1756: 383).
948 A draft version can be seen in Herschel's manuscript; RAS W.4/23.1: 7. It is presented in the title figure of this chapter.
949 RS MS/274.
950 RAS W.2/3.2.
951 An equal-area Mollweide projection is applied.
952 RAS W.2/8.5.
953 Herschel W. (1785c). The publication shows two added notes (below the text), mentioning observations of nebulae made on 1 and 7 February.
954 RAS W.2/24.1.
955 Herschel had now doubt that stars are distant suns: "We know that the sun, at the distance of a fixed stars, would appear like one of them; and from analogy we conclude the stars to be suns." Herschel (1783c: 130).
956 In the literature, this is sometimes asserted in connection with Herschel's star counts.
957 RAS W.2/8.2.
958 RAS W.4/24.1.
959 Herschel. W. (1795a).
960 Holden (1884). Edward Holden (1846–1914), American astronomer and Director of Washburn Observatory at Madison (Wisconsin). He discovered 17 NGC objects.
961 Col. John Herschel (1837–1921); John Herschel's third son was an English military engineer and astronomer, mainly working in India; see Shylaja (2006). Matilda Rose Herschel (1844–1914) was John Herschel's seventh daughter.
962 Dreyer (1912b: 699–711).
963 RAS C.3/1.1. Neither the *Royal Astronomical Society* (Herschel Archive) nor the *Royal Society* has Caroline's manuscript. A search in the Herschel family papers, archived at the *Harry Ransom Center* (University of Texas at Austin), also brought a negative result. Therefore, the author has extracted the gage data directly from Caroline's sweep records (RAS W.2/3).
964 Herschel W. (1802b).
965 The four open clusters are: NGC 2358 (VIII 45), NGC 2432 (VI 38), NGC 2479 (VII 58), NGC 2509 (VIII 1).

966 Herschel W. (1811).
967 Herschel W. (1811: 282).
968 Herschel W. (1817: 325).
969 Herschel W. (1818). The term ‘profundity’ is treated in section 4.2.3.
970 Herschel W. (1818: 463).
971 For the further development to reveal the structure of the Milky Way, see Rohlfs (1988).
972 RS MS/272.
973 This is Herschel’s Dolland refractor of 39 inches (3.5 feet) focal length.
974 Herschel noted: “I saw the star plainly double.” The double star was already found on 2 May 1780 in the second review and catalogues as II 19.
975 RAS W.4/1.7: 623.
976 RAS W.2/3.2.
977 Herschel W. (1785c: 256).
978 RAS W.4/1.7: 630.
979 Dick (2013: chapter 3.2) discusses the meaning of such voids as astronomical ‘objects’. B 86 refers to the catalogue ‘dark nebulae’ by Barnard (1919).
980 Barnard (1927: text to Plate 13).
981 Barnard (1897).
982 John observed at Feldhausen, near Cape Town, with an 18¼-inch front-view reflector. 382 sweeps were made; the first on 5 March 1834, the last on 23 January 1838.
983 Herschel Mrs. J. (1876: 258); Lubbock (1933: 372).
984 Herschel Mrs. J. (1876: 266); Lubbock (1933: 373); Evans (1969: 72).
985 Herschel Mrs. J. (1876: 269); Lubbock (1933: 373). That William spoke German to Caroline is unusual and may be due to the surprising view. Shaped by bad experiences in his home country, he was against everything German in language and word (even when corresponding with Bode or Schroeter). He was naturalized by an Act of Parliament on 30 April 1793.
986 Evans (1969: 143).
987 Johann Georg Hagen (1847–1930), Austrian Jesuit priest and astronomer; Director of Vatican Observatory in Castelgandolfo.
988 Clerke (1895: 67).
989 William Alfred Parr (1834–1936), English amateur astronomer.
990 Steinicke (2014d).
991 Herschel W. (1785c: 257).
992 Sweep 566 started in an unusual manner. William noted: “My sister swept by way of practise to myself of booking for her.” However, the essential observations were made by him, taking over after 25 minutes.
993 RAS W.2/8.2.
994 RAS C.3/1.1: 40, RAS W.2/7.

995 Dreyer (1912b: 712). Curiously, the 77 cases are not identical with those, listed by Caroline.

996 The regions are much more transparent in the infrared. Those images show many stars, shining through the dust.

997 Herschel W. (1785c: 216).

998 Barnard (1919, 1927). LDN means 'Lynds Dark Nebula'; Beverley Turner Lynds (*1929) is an American astronomer. She compiled the catalogue in 1960. LBN refers to her catalogue of bright nebulae.

999 Hoskin (1987: 18).

1000 Herschel J. (1833b: 376), Herschel J. (1869: 527).

1001 Hind (1853: 92).

1002 Steinicke (2014c).

1003 Herschel J. (1833a: Fig. 25); due to John's drawing, M 51 was also called 'ring nebula'.

1004 Hoskin (1987: 9–14).

1005 Fischer (1791: Fig. 16).

1006 Mitchel (1851: 186); Ormsby Mitchel (1809–1862), American astronomer.

1007 Chambers (1890: 110). George Chambers (1814–1915), English barrister, amateur astronomer and author.

1008 Herschel J. (1847: 375–379).

1009 Herschel J. (1847: 381).

1010 Hoskin (1987: 22).

1011 This wrong interpretation can be seen on several websites.

1012 Jacobus Kapteyn (1851–1922), Dutch astronomer; John Plaskett (1865–1941), Canadian astronomer. For the history of the discovery of the Milky Way see Jaki (1973), Belkora (2021).

1013 Herschel W. (1811).

1014 V 13 is M 8 in Sagittarius; V 17 is M 33 in Triangulum; V 28 is the Flame Nebula (NGC 2024) in Orion; V 30 is NGC 1977 in Orion; V 31 is the ι Orionis Nebula (a part of M 42); both V 33 (NGC 1908) and V 38 (NGC 1909) in Orion do not exist; V 34 is NGC 1990, the non-existent 'ε Orionis Nebula'.

1015 Steinicke (2010a: chapter 12.6.15).

1016 Barnard noticed the large nebula in 1894 on a plate, Barnard (1894). Herschel saw the brightest, north-eastern part.

1017 For a different view, see Latussek (2009).

1018 Herschel W. (1811: 336, Plate IV & V); Dreyer (1912b: 480, 496).

1019 Herschel W. (1814).

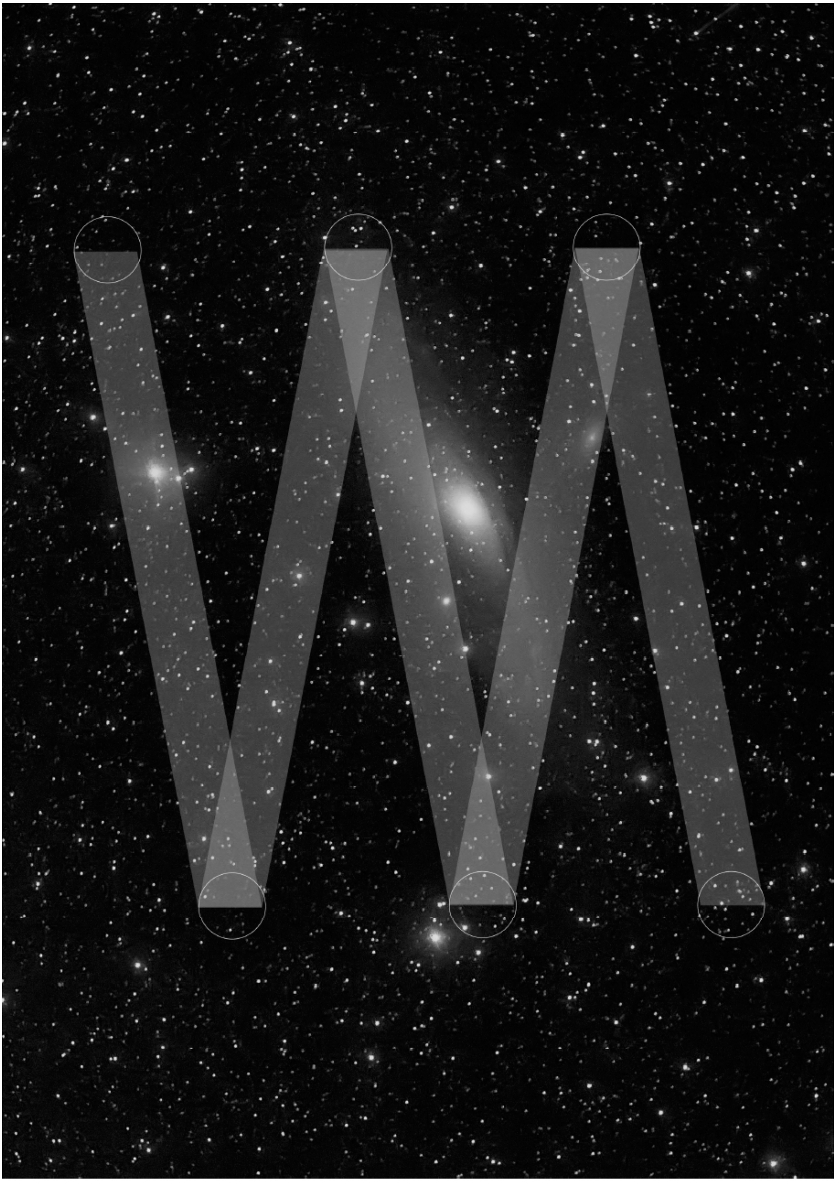
1020 Herschel W. (1814: 284, Plate IX), Dreyer (1912b: 537).

1021 Herschel W. (1817).

1022 Herschel W. (1818).

1023 Herschel W. (1818: Plate XXI).

5. Modern analysis of Herschel's data



This chapter is an examination of Herschel's methods, observational data and results from a modern point of view. The amount of information, left by William and Caroline, is huge and only manageable with the aid of the computer. Of course, this required the digitization of numerous handwritten documents and published papers, like the three Herschel catalogues of nebulae and star clusters.

The resulting digital data offer the potential to obtain the answer to a multitude of questions that previously could not be addressed by former authorities, especially John Herschel and John Louis Emil Dreyer. A major issue is William's sky coverage (total area covered by the sweeps) and success rate (discovered objects in the reach of his telescope). The results of the thorough analysis are tables and graphics, shown in this book. As always, every insight gives rise to new ideas and, of course, further questions.

5.1. Sweep method and its yield

5.1.1. Relevant documents, digitization and important questions

Most documents containing sweep data were managed by Caroline. She created the records and various tables and charts, derived from the observational data. They concern objects, sweep areas, reference stars, positions and much more. Table 5-1 lists the important original documents, related to Herschel's sweep campaign. Some belong to a series, like the *Journal* or *Fixt Stars*. They are ordered by their archive number of the *Royal Astronomical Society* or the *Royal Society*. All documents are treated in the previous sections of this book (compare, for instance, Table 2-5). Of course, there are other documents, like the *Review* series, concerning stars (single, double, multiple) or Solar System objects.

Document	Archive	Name, content, remarks
Sweeps No. 1–7	RS MS/272–278	Sweeps 46–1113 (called 'Original')
A Catalogue of the	RS MS/279	*Zone Catalogue*:

Nebulae which have been observed by Wm. Herschel in a series of Sweeps; brought into Zones of N.P. Distance and order of RA. for the years 1800		number, class, date, reference stars, positions (1800), sweeps; work started October 1816 and ended March 1825
Records of Nebulae	RS MS/339–343	One sheet for each of the 2508 Herschel objects
Messier's Nebulae & Stars Clusters	RS MS/344	One sheet for each of the 103 Messier objects
The Right ascension & Polar Distance brought to Jan. 0, 1800 of the 2500 Nebulae & Clusters of Stars printed in the Phil. Trans. According to their Gen. Number	RS MS/345	'2500 Nebulae', number, position (1800), sweeps; finished in spring 1804
General Catalogue of new Nebulae and clusters of Stars	RS MS/346	'General catalogue', number, class, date, reference star, position (1790), sweep; closed in October 1802
Flamsteed's Catalogue brought into Zones	RAS C.2/1.1–3	Stars PD 0°–126°, position (1690/1785), precession
Journal No. 7–10A	RAS W.2/1.7–10A	Sweeps 1–350 (by William)
Sweep Records No. 1–8	RAS W.2/3.1–8	Sweeps 46–1112, revised version (1800); started in June 1799, finished 16 March 1804
Catalogue of omitted Stars	RAS C.2/4.2	Stars, observed by Flamsteed, but not found in the *British*

		Catalogue
Sweeping Concerns	RAS W.2/7	Vacant places, 'half swept' areas, stars for Wollaston (M.S.), crowded areas, polar region, gallery positions, field orientation etc.
Register of Nebulae	RAS W.2/8.2	Sweep chart PD 45°–117°
Register of Sweeps according to the time of observation	RAS W.2/8.3	Sweep chart PD 30°–123°
Register of Sweeps according to the time of 1690	RAS W.2/8.4	Chart of nebulae positions PD 47°–123°
Register of Gages	RAS W.2/8.5	Number of counted stars in a field
Temporary Index (original & copy)	RAS C.3/1.1–2	Stars (new, lost, coloured, periodical, double), vacant places, weather etc. (closed 1813, copy closed 1817)
Sweeps calculated for 1800	RAS C.3/2.1	'Sweep list', Positions of sweep areas 46–1112
A Catalogue of the Stars which have been observed by Wm. Herschel in a series of Sweeps; brought into Zones of N.P. Distance and order of RA. for the years 1800	RAS C.3/2.3	Observed and reference Stars (Flamsteed, Wollaston, Bode), double stars (N), unknown stars (U); made in 1802
Fixt Stars Vol. 5–7	RAS W.4/1.5–7	Sweeps 1–236, 'first copy'
Catalogue of 1000 new Nebulae in Classes	RAS W.4/25.1	First Herschel catalogue (draft)
Catalogue of a 2nd	RAS W.4/26.1	Second Herschel

thousand of new Nebulae etc.		catalogue (draft)
Catalogue of 500 additional new Nebulae and Clusters of Stars	RAS W.4/28.2	Third Herschel catalogue (draft)
Nebulae of the Connoissance des temps / Observations of the Nebulae of the Connoissance des temps / Neb. Of the Conoiss.	RAS W.4/33.1–3	Description, dates, positions (various tables)
Planetary Nebulae pointed by Stars	RAS W.4/33.4	Finding charts ('star-hopping')
General Index for Nebulae	RAS W.4/33.5	Class, number
Several Catalogues & Indexes of Neb. & Clusters of stars used before their General catalogue was introduced	RAS W.4/33.6	First object lists, positions (1690)

Table 5-1: Documents containing sweep data, sorted by their archive designation (RS = *Royal Society*, RAS = *Royal Astronomical Society*). The *Journal* is written by William, all other documents by Caroline.

Of course, the computer is the ideal tool to analyse these data. But this requires the digitization of numerous documents and papers – not an easy task. Due to the lack of reasonable alternatives, the information must be entered by the keyboard. This takes time and persistence – but the reward is immense. The digital data bear the potential to get answers for a wide range of questions. Due to their amount, the combination of various information is almost endless. However, many relations cannot be gained directly from the original data, they need sophisticated software tools, developed for special purposes. The results are listed in tables or visualized by graphics. Here are some typical questions, treated in this section:

- What is the effective sky coverage of all sweeps?

- In which sweep(s) lies, or could lie a certain object?
- Were all objects (visible in the 20-ft) actually found?
- How many objects did Herschel discover?
- What is the distribution of the Herschel objects on the sphere?
- How precise are the determined positions?
- How do the brightness and size values fit to modern ones?

Of course, every insight creates new ideas and further questions. The many tables and graphics in this book, which depict specific topics and situations, are results of the process described here.

5.1.2. Sky coverage and Herschel's success rate

To treat the question about the sky coverage, one must analyse Herschel's sweeping method in detail. This can be done best for a long and effective sweep. The top scorer is sweep 396, made on 11 April 1785 in Leo Minor and Coma Berenices (see section 2.3.3, especially Figure 2-84). Caroline's sweep record gives the basis data:

- mean PD/declination: 62° / $+29^\circ$
- PD range (sweep breadth): D = 2.3°
- AR range (observing time): R = $3^h\,36^m$

Any sweep covers a (nominally) rectangular area on the celestial sphere, given by A = R × D (Figure 5-1). To get A in deg^2, the right ascension must be converted by the following formula (dependent on declination; the sign is irrelevant):[1024]

$$AR(^\circ) = 15 \cdot AR(h) \cdot \cos \delta$$

This implies that the AR, measured in degrees, decreases towards the pole. At $\delta = +29^\circ$, 1^h corresponds to 13.1°. Thus, we get: $A = 47.2^\circ \times 2.4^\circ = 113.4$ deg^2.

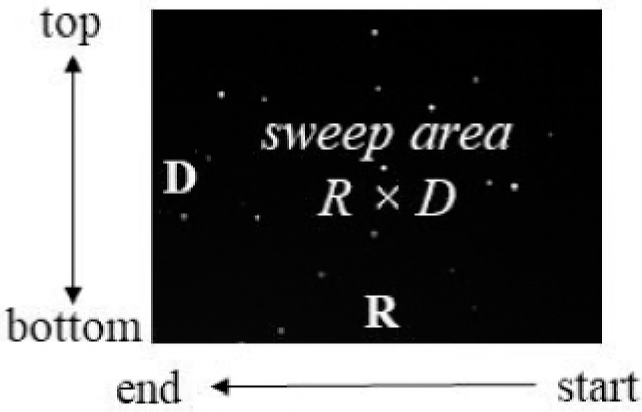


Figure 5-1: Nominally the sweep area is a rectangular portion of the sky. The horizontal side is the RA range (R), the vertical side is the breadth (D). In some sweeps, objects (mainly stars) were observed beyond the top/bottom limits.

Let's now ask a heretical question: Did Herschel see all possible objects (stars, nebulae or clusters, visible in his 20-ft telescope), located in this area? Although the *Atlas Coelestis* shows 13 Flamsteed stars for sweep 396, Caroline's record mentions only 10, of which eight were later taken as reference stars. Thus, three stars were not observed (24 LMi, 9 Com, 10 Com). How about the non-stellar objects? The NGC/IC catalogue lists 142 candidates in the sweep area, which are visually (by their magnitude and size) in the reach of the 20-ft. The record contains 'only' 71 of them (all are galaxies). What is the reason for the difference?

This is a fundamental question. To answer it, one must understand Herschel's sweep method. By the 'sweeping motion', the tube of the 20-ft can only move up or down in the meridian (fixed azimuth). Of course, any observing would be useless without the rotation of the Earth. We would only cover a vertical area A, limited by the field of view and the breadth D (in our case A = 15' × 2.4°). Because of the rotation, the sky constantly 'moves' from east to west at a constant speed (15° per hour). The projection of the combined motion (up/down, east to west) on the sphere is the 'sweep path'. If the 'sweeping motion' is constant too, the path draws a zigzag pattern, whose tightness depends on the speed of the 'sweeping

motion' (Figure 5-2). Here is the essential point: the pattern does not cover the sweep area, there are periodic triangular gaps in the upper and lower part. Of course, there is a certain (higher) sweep speed at which all gaps disappear – we then have a full coverage.

Figure 5-2: The zigzag pattern of the sweep path. Its tightness depends on the speed of the vertical 'sweeping motion'; left: low speed (the nebula in the gap is not seen), middle: higher speed, right: speed does not lead to any gaps (all objects seen).

Instead of sweep speed we can take the time T to cross the breadth D (Figure 5-3). Assuming a mean declination of $\delta = 0°$ (sweeping at the celestial equator), we get a simple formula for the coverage C, where T is the sweep time in minutes:

$$C = \frac{4T - 1}{4T^2}$$

Note that C depends only on T; R and D do not occur! $C = 1$ means full coverage (100%). The critical time for $C = 1$ (no gaps) is $T = 0.5$ min. For $T = 1$ min we have $C = 0.75$, i.e. the area A is 75% covered. For $T = 2$ min, the value decreases to 44%. Since large T means low sweep speed, the basic result is: the lower the sweep speed, the larger the gaps. A coverage below 100% automatically means that certain objects will be missed; they are located in the gaps.

For $\delta \neq 0°$, T must be replaced by $T \cdot \cos\delta$ in the above formula. For a fixed time T, the coverage increases with declination (Figure

5-3). Taking T = 2 min, we have 44% coverage for $\delta = 0°$, 50% for $\delta = 30°$ and as much as 75% for $\delta = 60°$. Thus, more objects can (in principle) be seen at higher declination. In other words, for the same coverage, you can take more time: for 75% you have T = 1 min at $\delta = 0°$ and 2 min at $\delta = 60°$. This makes northern sweeps more relaxed.

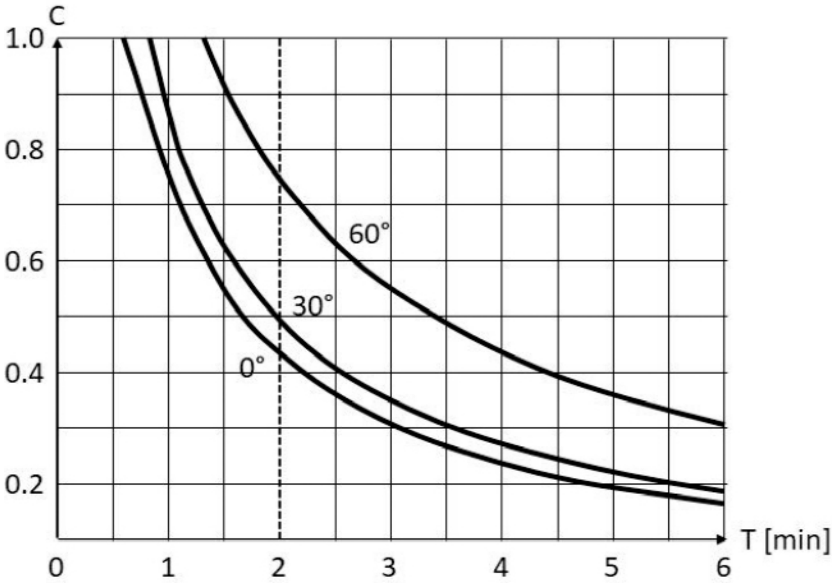


Figure 5-3: Time T and coverage C for different declinations (see text).

What does this mean for the non-stellar objects in the record sweep 396 at $\delta = +29°$? If one roughly assumes 63% coverage (due to the ratio 71/142 of seen objects to all), we get T = 1.5 min to cross the breadth D = 2.4° = 144'. The sweep speed is then 96'/min. Because 1 FoV = 15', about 10 fields fit into the breadth. Thus, Herschel had less than 10 seconds for a single field. If there is no object, this time is fine. But for complex situations (object with remarkable features or several objects), the time is too short for a detailed recording of the field content.

This fact has great influence on the sweep pattern. In practice, it cannot be the regular zigzag pattern of Figure 5-2. In case of an unknown object, Herschel halted the sweep motion by a command

to the workman at the bottom. We must realize that any stop leads to a step in the horizontal sweep path. One can even track an object by the ‘side motion' over several fields of view (the time depends on declination). This causes an even larger step and, consequently, the gap in the sweep area increases – and thus the number of missed objects. A slower sweep speed is not a solution: this makes it more difficult to determine the position. On the other hand, if a region offers nothing remarkable, one may even increase the speed; the result is a steeper path with less gaps, offering a greater chance for a discovery.

With the aid of a special software, the actual sweep pattern can be reconstructed, but that is quite an effort. The tool was applied to sweeps with a certain variety of parameters, made in various sky regions with different object distributions. The result is clear: the true sweep path usually deviates largely from the theoretical one (Figure 5-4). It shows that Herschel used the up-down-mode as long as no interesting object was seen.

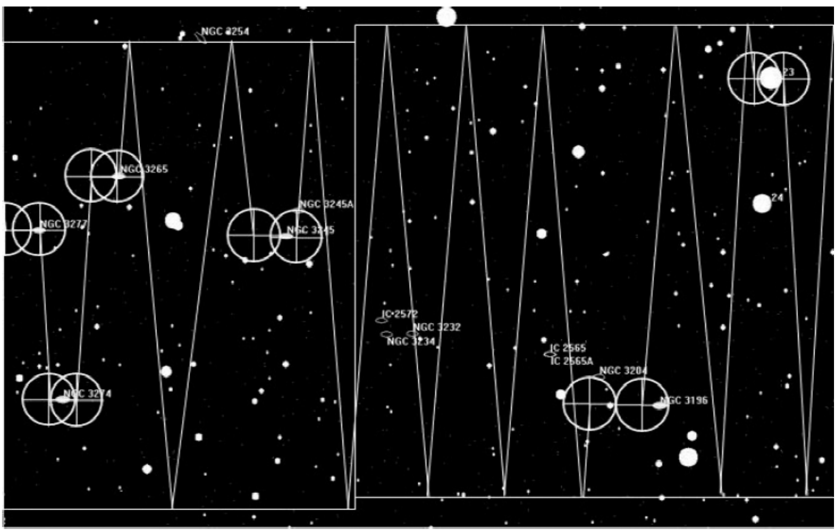


Figure 5-4: This 18-minute part of sweep 396, shortly after it started, shows a complex sweep pattern (only the central line is shown). We see a mix of oblique and horizontal lines. The sweep speed (slope) varies, but was generally pretty high. In case of an object (star, nebula), the ‘sweeping motion’ was halted and the object tracked, creating a horizontal path (step in the pattern). One

star (23 Leo) and five galaxies were seen: NGC 3196, NGC 3245, NGC 3265, NGC 3274, NGC 3277 (filled ovals). All other objects in the sweep area, were missed, due to gaps (24 Leo, NGC 3234), or faintness (NGC 3232). Note that the PD was lowered by 8' in the sweep.

However, there is a much more homogeneous situation: a 'star gage' with 10 fields, counted along the sweep path and covering the whole breath (see section 4.1.2). The configuration makes it possible to determine relevant sweep parameters. Because only the central AR and PD are given in the record, one cannot get the time T or the sweep speed. But this is different, when adjacent gages were taken, not interrupted by any other object, like a star or nebula. From just two gages, one gets the time difference between the central positions, due to the readings of the sidereal clock. Based on the known breadth, the sweep speed can now be calculated.

However, the simple situation does not imply that the sweep path is a straight line. If the fields in the row show too many stars, counting takes time and probably the motion must be stopped. In this case, the path is more of a staircase than a straight line.

Sweep 220, made with D = 2° 10', gives an example. It contains two successive 10-field gages.[1025] The time to cross the breadth was 5 minutes, which implies a sweep speed of 26'/min (significantly slower than the 96'/min, derived in the theoretical view). Because the mean number of stars in a field was only 12 a straight line is reasonable. If the motion is slow enough, no stop is needed. Note that we speak here about simple counting instead of describing objects.

A much faster case is the following. In sweep 222, Herschel performed no less than six adjacent 10-field gages.[1026] In the first, the star number was exceptionally low (1 on average). Things now went fast: the breadth (2°) was crossed in two minutes, getting a sweep speed of 60'/min. Of course, the paths were straight lines.

Generally, the mean sweep speed for a 10-field-count over the full breadth varies between 10'/min and 60'/min (24'/min on average). There is a fairly good correlation with the star numbers, a measure

of the effort. Interestingly, the highest speed (138'/min) was reached in the monster sweep 396. The gage was taken near the end.[1027] What was the cause for the fast gage? Sweep 396 brought a large number of new nebulae, thus it is likely that Herschel did not want to waste much time with gaging, but, nevertheless, was interested to register the star density in the ‘stratum of Coma Berenices’.

Regardless of the specific sweep pattern, the basic fact remains: the method produces gaps which implies that only a fraction of all visible objects can actually be seen. The rest is lost. Maybe another sweep, made in the region, would show some of them. Herschel was fully aware about this issue and his strategy was simple: repeated, overlapping sweeps. The control was, as usual, laid in the hands of Caroline. Her ‘Register of Sweeps’ shows all sweeps between PD 30° and 124°, plotted on 37 large charts.

An interesting question is the total sky area, nominally covered by all sweeps, i.e. not considering the internal gaps. On can get an impression by Caroline’s sweep register.[1028] The maps clearly show that not the whole sky, visible from the Windsor area, was covered.

The next goal is to determine the actual value of Herschel’s sky coverage. This can be done by another product of Caroline’s sweep list.[1029] The large table gives the AR and PD limits for sweeps 46 to 1112 (Figure 5-5). To get the corner coordinates of the rectangular sweep area, she used a reference star, observed in the sweep (noted in an extra column). About 12% of the listed sweeps are marked ‘Not to be Registered’. They were soon terminated, due to upcoming clouds/haze, instrumental defects (telescope, clock) or other incidents. There is also a medium category between all or nothing, named ‘half swept’.[1030] This means that the sweep was partly influenced by twilight, moonlight, haze or anything similar, but was not terminated. This concerns about 5% of all sweeps. However, the attribute ‘half swept’ was not used very strictly.

After Caroline’s sweep data were digitized, the way was paved for a (first) quantitative treatment of the nominal sky coverage. However, due to the unknown overlap, one cannot simply sum up all sweep areas. To eliminate the overlap, one must consider the outer border of the total area, taking into account that it is multi-

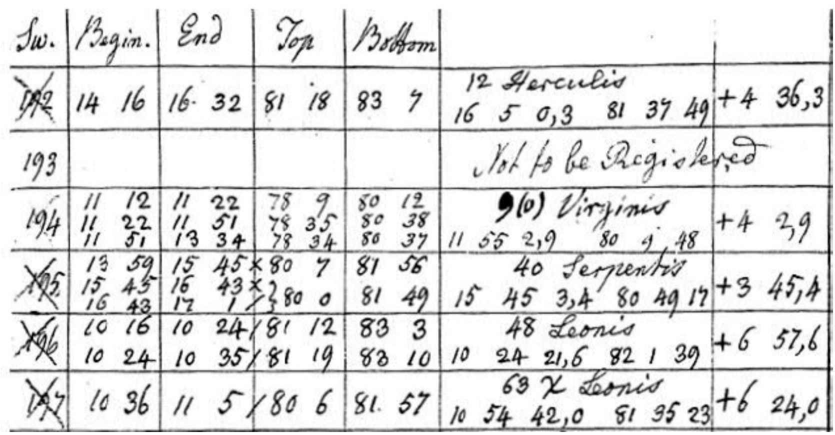
connected (i.e. there are 'islands'). The calculation needed a special algorithm. Due to Herschel's endurance, the result is not astonishing: the sweep areas cover about 90% of the sky (Figure 5-6). There are three regions in which, for different reasons, no or relatively few sweeps were performed:

(1) *polar region*: due to the slow sky motion, sweeping was time consuming and had a lower priority,

(2) *west of the summer Milky Way*: due to short summer nights, sweeping was difficult,

(3) *east of the winter Milky Way*: sweeping in winter in the north at high elevation was dangerous.

However, due to the rectangular projection, the non-swept regions look larger than they really are. Another factor is the lack of reference stars in the north.



Sw.	Begin.	End	Top	Bottom		
192	14 16	16 32	81 18	83 7	12 Herculis 16 5 0,3 81 37 49	+4 36,3
193					Not to be Registered	
194	11 12 11 22 11 51	11 22 11 51 13 34	78 9 78 35 78 34	80 12 80 38 80 37	9(o) Virginis 11 55 2,9 80 9 48	+4 2,9
195	13 59 15 45 16 43	15 45 16 43 17 1	80 7 80 0	81 56 81 49	40 Serpentis 15 45 3,4 80 49 17	+3 45,4
196	10 16 10 24	10 24 10 35	81 12 81 19	83 3 83 10	48 Leonis 10 24 21,6 82 1 39	+6 57,6
197	10 36	11 5	80 6	81 57	63 χ Leonis 10 54 42,0 81 35 23	+6 24,0

Figure 5-5: Part of Caroline's table 'Sweeps calculated for 1800'. Often a sweep has several parts; e.g. when the upper/lower PD limit was changed.

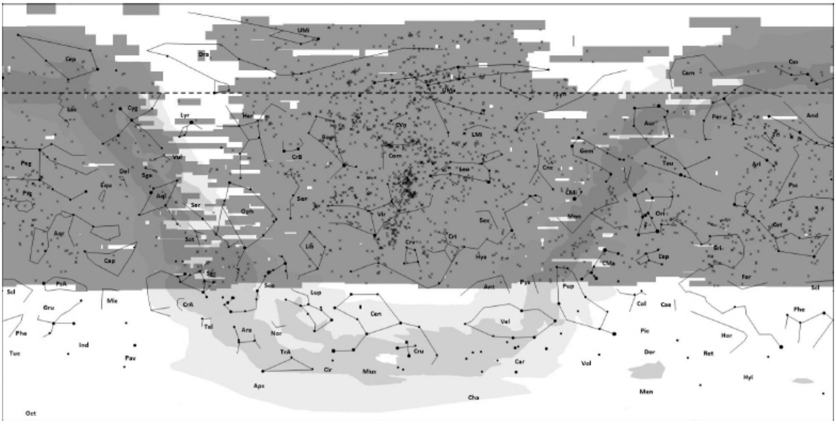


Figure 5-6: Nominally, the sweep areas (grey) cover about 90% of the visible sky (rectangular projection). Also shown are the observed stars (dot) and the discovered non-stellar objects (cross); compare the coloured version on the back cover. Above the dashed line, sweeps were made in the north. Note the three regions with few sweeps (near the pole, west of the summer Milky Way and east of the winter Milky Way).

Special attention is paid to the area within 20° of the north celestial pole. The polar projection (Figure 5-7) shows that a 10° wide strip from 6^h to about 18^h was not swept by Herschel. Additional to the discovered objects, all brighter stars are shown here (whether observed or not); they were taken from the *Yale Bright Star Catalogue*. The two 'wedges' pointing towards the pole refer to the 'not registered' sweeps 724 and 759, made on 7 April and 19 September 1787, respectively (in the rectangular projection of Figure 5-6 both areas appear at the upper left border). The small strip at lower right is the 'not registered' sweep 753, made on 11 September 1787.

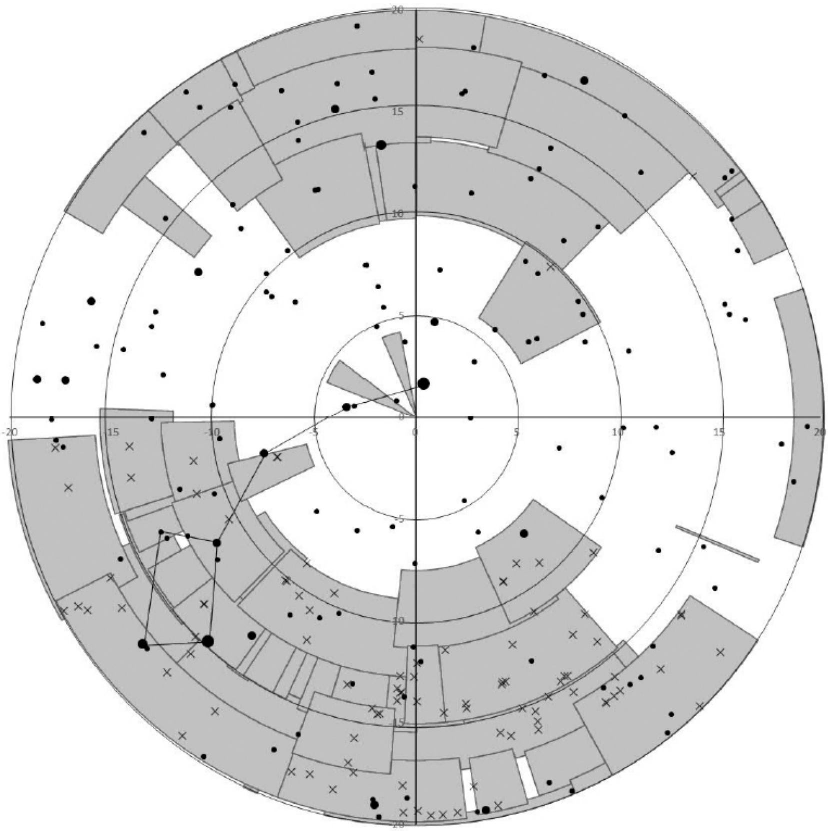


Figure 5-7: Northern sweeps in the polar region (PD < 20°); 0^h is at the top, 6^h right (polar projection); x = discovered Herschel objects; all stars brighter than 6.5 mag are shown (whether observed or not); see the coloured version on the back cover.

Figure 5-8 demonstrates the progress of covering the sky over the years, showing the sweeps for the three Herschel catalogues separately. The accompanying sweep areas appear in different grey levels; additionally, all Flamsteed stars are presented. Many of them were taken as reference stars.

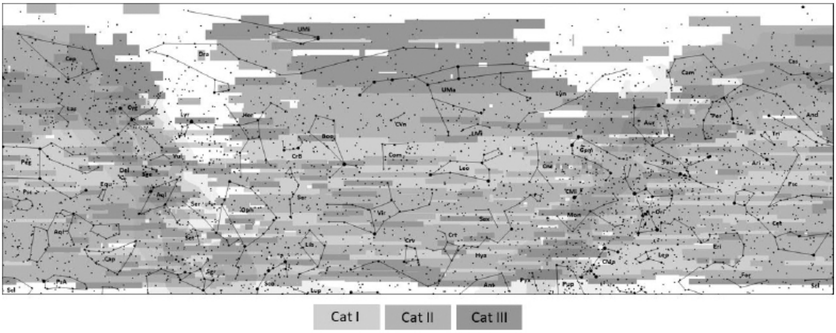


Figure 5-8: Sweep areas related to the three catalogues. Most sweeps for the third catalogue were made in the north; all Flamsteed stars are plotted.

What about the overlap? The value can be derived by a simple calculation. The total sky area (lateral surface of the sphere) between PD 0° to 123° is 31,973 deg². If 90% of it is nominally covered, we get an area of 28,775 deg². On the other hand, the sum of all 1112 sweep areas is 45,265 deg². Thus, we get a ratio of 28,775/45,265 = 0.64, giving a 36% overlap of the sweep areas (Figure 5-9).

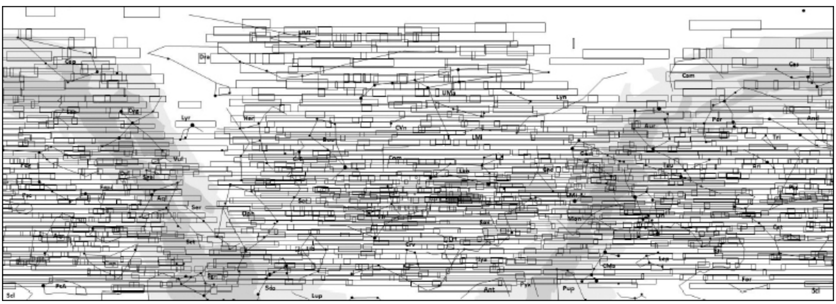


Figure 5-9: The contours of the sweep areas show the overlap (only the brightest stars are plotted).

Can we determine the sum of all gaps in the sweeps? Of course, this is impossible! It would mean that we knew the actual path for each sweep. A stupid idea would be to join the recorded objects in a sweep by straight lines. Doing this, for instance, for sweep 396, we get an impossible pattern (Figure 5-10). It would mean that Herschel already knew the place of the next new object! However,

given the deviations from a regular sweep pattern, it often seems like he suspected new objects and showed some instinct for where to find them. When there was a high density of nebulae, like in the 'stratum of Coma Berenices', he got from one to the other with seemingly dreamlike certainty – a mysterious matter.

Fortunately, there is a statistical approach to tackle the gap problem. It implies missing objects and is based on the question: What is the ratio of non-stellar objects Herschel observed to all that were visible in his 20-ft reflector due to brightness and size? To get the potential objects, our first choice is the NGC/IC. The catalogue is almost complete in terms of visually discovered brighter nebulae and star clusters, though by different observers with various telescopes. Of course, Herschel was the main contributor to the NGC (the IC mainly contains non-stellar objects, found by photography).

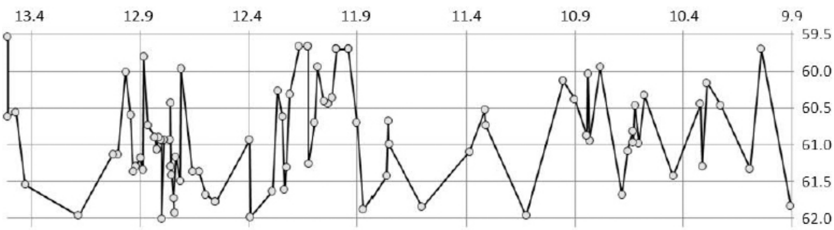


Figure 5-10: If we connect all objects, seen in sweep 396, we get an impossible pattern. It would presume that Herschel already knew where to find them!

The query gives 3523 NGC/IC objects in total. As we will see in Table 5-10, William discovered 2447 of them. The remaining 1076 were found by other observers; of course, John was the main contributor (Figure 5-11). Thus, the resulting ratio is 2447/3523 = 0.7, which means that 70% of the possible objects were actually seen. Though William was able to see the remaining objects, there was no chance for the most of them: they never entered his field of view. Of course, there will be small number of objects that were simply overlooked, but anyway, Herschel's success rate is unbelievable. Now, we have a statistical measure for the gaps: they comprise about 30% of the total sweep area.

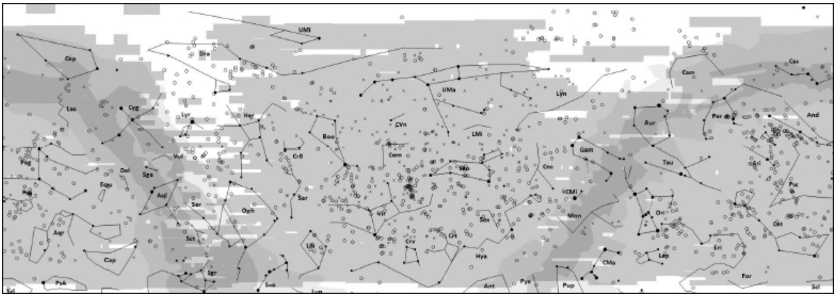


Figure 5-11: Distribution of the 1076 nebulae and star clusters, being in the range of Herschel's 20-ft, but missed due to the sweep patterns. 364 were later found by John (x) and 701 by other observers (o); the brighter stars are shown.

Theoretically, William had two possibilities to increase his fantastic yield: (1) higher sweep speed, (2) larger sweep overlaps. Concerning the first, the siblings were already working at the limit of their capabilities, concerning observation, recording and evaluation. Any acceleration would mean more stress, thus more errors – and probably more missing objects. Moreover, the technical resources were almost exhausted. Thus, (1) is counterproductive. Choosing (2) would imply extra time, which William did not have. After 20 years of sweeping and already 64 years old in September 1802, he was exhausted and happy to close the campaign. Visual observing, as he practiced it, was a task close to the edge. His endurance and accuracy over such a long time are unmatched in astronomy. There was no need for any further action. Caroline must have been happy too!

5.2. The content of Herschel's deep-sky catalogues and sweep statistics

5.2.1. Reference stars and Caroline's list of all observed stars

An interesting theme are the reference stars, used to get the position of objects (Table 5-2). In the first period, Herschel determined the places were from sketches of the finder and telescopic views. In sweep 42, made on 13 December 1783, a Flamsteed star is

mentioned for the first time. The *British Catalogue*, contained in the third volume of the *Historia Coelestis Britannica* (published 1725), had been purchased already in 1774. In the north, Herschel took stars from the Hevelius catalogue. If no star was available, he also used known non-stellar objects for refence (see Table 2-27 and Table 6-3).

Author (type)	Sw	Date	Object	Source	Rec	Remarks
Flamsteed (star)	42	13 Dec. 1783	8 Cet	*Historia Coelestis* (1725)	1774	1690, *British Catalogue*
WH (nebula, cluster)	74	30 Dec. 1783	M 98			
Hevelius (northern star)	101	23 Jan. 1784	12 Cnc	*Historia Coelestis* (1725)	1774	1660
WH (omitted star)	104	23 Jan. 1784	O170	*Catalogue of Stars* (1798)	1798	1800, Caroline
WH (unknown star)	358	27 Jan. 1786	U422			
Lacaille (star)	550	28 Mar. 1786	1102 e Hya	*Coelum Aust. Stell.* (1770)	1786?	1759, French edition
Wollaston (star)	878	1 Nov. 1788	7 Cam	zone catalogue (1789)	1787/88	1790, proof sheets
Tobias Mayer (star)	913	20 Mar. 1789	Mayer 522	Wollaston (1789)	1789	1790
WH (planet)	-	22 Mar. 1794	Uranus			
WH (double star)	1066	10 Dec. 1797	N118			
Bode (star)	1100	8 Nov. 1801	8 UMi	*Uranographia* (1801)	1801	1801

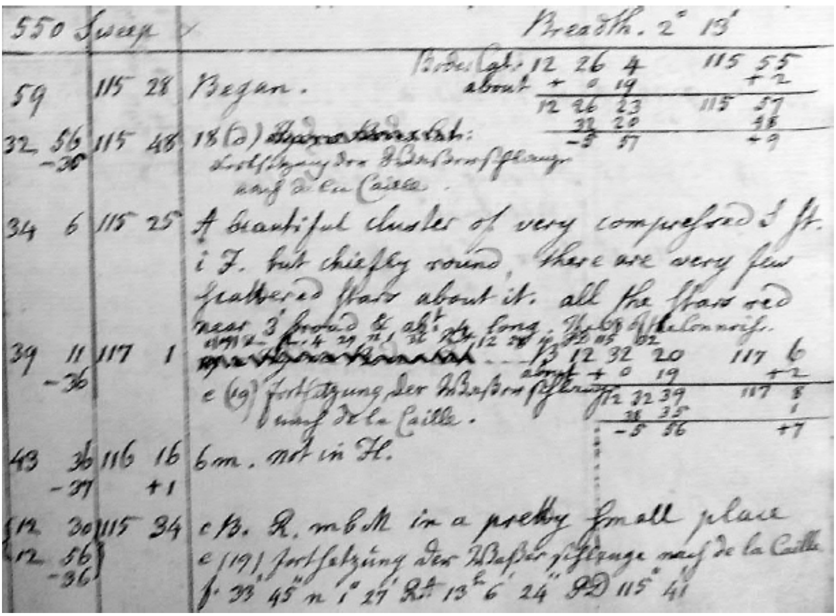
Table 5-2: Reference objects (star, non-stellar, planet) and their first use. Source (publication year); Rec = received by Herschel (year); Remarks: year = equinox.

There are about 500 Flamsteed stars, which were observed by the first Astronomer Royal but not included in his catalogue. Based on William's observations, Caroline has carefully collected them. The result was published in her *Catalogue of Stars* of 1798. There were also 1117 'unknown stars', not included in the published catalogues prior to about 1788.

On 28 March 1786, Herschel used a star from Lacaille's catalogue *Coelum Australe Stelliferum*, covering the southern hemisphere. The French edition, published 1770, must have been purchased earlier. It gives positions for 1660. Caroline's 'original' record for sweep 550 is most interesting (Figure 5-12). The two stars '18 (d)' and 'e (19)' show a comment in old German handwriting ('Sütterlin script'): "Fortsetzung der Wasserschlange nach de la Caille" ("continuation of Hydra after Lacaille").[1031] The term 'continuation' refers to Flamsteed's treatment of Hydra in the *British Catalogue*. There the constellation is split into two parts: 'HYDRÆ', listing stars 44 stars, and 'HYDRÆ Continuatio' with another 16. In Lacaille's catalogue the stars are numbered; brighter ones have letters (Figure 5-13). It is astonishing that Herschel did not use Lacaille's numbering, which would give 1094 for 'd Hydrae' and

1102 for ‘e Hydrae’. Instead, the first appearance of a star in Hydra is given no. 1. Counting to the two stars, one gets no. 18 and 19, which explains ‘18 (d)’ and ‘e (19)’. When Caroline later used Wollaston’s zone catalogue, she noticed that the stars are listed as ‘d Hydrae L.C. 1094’ and ‘e Hydrae L.C. 1102’.

In 1787/88, Caroline received proof sheets of Wollaston’s star catalogue (to be published in 1789). The stars, taken from Flamsteed, Hevelius, Lacaille and Mayer, are arranged in PD zones from 0° to 180°. The first stars were used by Caroline in sweep 878 (1 November 1788): 7, 13 and 17 Camelopardalis Hevelii. The new catalogue was also her source for objects from Tobias Mayer’s *Catalogue of Zodiacal Stars*.1032 The first star, Mayer 522 in Virgo, was used on 20 March 1789 (sweep 913).


550 Sweep

Breadth. 2° 13′

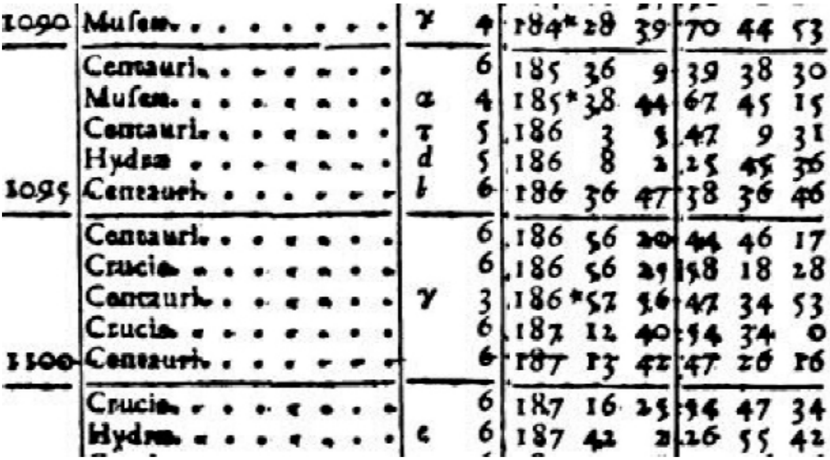
59 | 115 28 | Began.

34 6 | 115 25 | A beautiful cluster of very compressed S st. i F. but chiefly round, there are very few scattered stars about it. all the stars red near 3′ broad & abt. long.

43 | 116 16 | 6m. not in Fl.

c B. R. mbM in a pretty small place

Figure 5-12: Caroline’s ‘original’ record for sweep 550 (28 March 1786) mentions two Lacaille stars (see text).



1090	Muscæ	γ	4	184* 28 39	70 44 53
	Centauri		6	185 36 9	39 38 30
	Muscæ	α	4	185* 38 44	67 45 15
	Centauri	τ	5	186 3 5	47 9 31
	Hydræ	d	5	186 8 2	25 45 36
1095	Centauri	b	6	186 36 47	38 36 46
	Centauri		6	186 56 20	44 46 17
	Crucis		6	186 56 29	58 18 28
	Centauri	γ	3	186* 57 56	47 34 53
	Crucis		6	187 12 40	54 34 0
1100	Centauri		6	187 13 42	47 26 16
	Crucis		6	187 16 25	54 47 34
	Hydræ	e	6	187 42 2	26 55 42

Figure 5-13: Part of Lacaille's catalogue *Coelum Australe Stelliferum* with the stars 'd Hydrae' (1094) and 'e Hydrae' (1102).

The next milestone was Bode's *Uranographia*, published in 1801. The Berlin astronomer has compiled all stars from Flamsteed (as given by Wollaston), Lalande, Hevelius, Mayer, Lacaille and a few other less important sources. Herschel received the large star duo of atlas and catalogue on 24 September. The first star, taken from Bode was 8 UMi in sweep 1100 on 8 November. Though the catalogue came too late for the daily work, it was essential for Caroline's revision of the sweep records, already started in 1799. She identified many 'unknown stars'. Together with Wollaston's zone catalogue there now was a wide fundus of reference stars to determine reliable positions of the observed objects. The result can also be seen in Caroline's *Zone Catalogue* (see section 6.1).

Based on the data in the sweep records, Caroline compiled a list of all stars, observed in the sweeps. The important document is titled 'A Catalogue of the Stars which have been observed by Wm. Herschel in a series of Sweeps; brought into Zones of N.P. Distance and order of RA. for the years 1800'.[1033] The list is organized in tables, each representing a PD zone. The first zone covers the pole region from PD 1° to 10°, the following have a breadth of 1°, starting with PD 11° and ending with PD 124°. A total of 3615 stars are listed. However, the sweeps records contain 23 additional ones, missed by Caroline. Table 5-3 shows all 3638 observed stars, concerning their source (catalogue) or nature.

Star	Number	Remarks
Flamsteed	2095	
Bode	872	
T. Mayer	60	
Hevelius	20	
Lacaille	32	
reference	1063	
manuscript (M.S.)	47	sent to Wollaston
unknown (U)	1117	659 identified
omitted (O)	142	of 561
double (N)	106	of 145
garnet/red	28	

Table 5-3: Observed stars, used by Caroline in the sweep records (the categories partly overlap).

The most northern star, seen in a sweep, is U^{1107} (HD 144463, 7.0 mag) in Ursa Minor; it has a polar distance of only 5° 49'.[1034] It appeared in the northern sweep 1106, made on 1 January 1802 under the pole. What about Polaris? Though the pole star was observed in the second star review (and found to be double), it was never seen in a sweep (see Figure 5-7). The most southern star, ι PsA (4.3 mag) at PD 123° 56', appeared in sweep 1053 on 27 September 1793. Table 5-4 presents the brightest stars, seen in the sweeps.

Name	Bayer	V	Sweeps	Remarks
Sirius	α CMa	-1.46	365, **366**	
Arcturus	α Boo	-0.05	170	
Vega	α Lyr	0.09	1109	not in C's star list
Capella	α Aur	0.03 – 0.16	645	double star VI 30
Rigel	β Ori	0.05 – 0.18	468, 516, 517, 554, 556, **654**, **656**, 782	double star II 33
Procyon	α CMi	0.34	156	not in C's star list
Betelgeuse	α Ori	0.00 – 1.60	156, 309, **496**	double star VI 39
Altair	α Aql	0.76	440	double star VI 46
Aldebaran	α Tau	0.75 – 0.95	292, 1093	double star VI 66
Antares	α Sco	0.60 – 1.60	**223**, **365**, **366**	
Spica	α Vir	0.97 – 1.04	**210**, **819**	
Pollux	β Gem	1.14	79, **385**	double star VI 42
Fomalhaut	α PsA	1.16	**430**	
Deneb	α Cyg	1.21 – 1.29	**867**, 959, 969	double star N73
Regulus	α Leo	1.39	51, 164, 177, **188**	double star VI 11

Table 5-4: The brightest stars, seen in the sweeps (some are variable). The bold numbers indicate the use as reference star.

Deneb was found as (optical) double star N73 in sweep 959 on 11 September 1990.

5.2.2. Catalogued, uncatalogued and missed objects

How many objects did Herschel actually discover? The question cannot be answered straightforward. Four problems need to be examined first:

(1) *Completeness problem*. In addition to the catalogued objects, also the uncatalogued ones must be considered.

(2) *Identity problem*. All cases of identical objects (referring to different entries) must be determined.

(3) *Type problem*. True non-stellar objects must be separated from unwanted types, like stars.

(4) *Discovery problem*. It must be ascertained which objects can actually be credited to Herschel and were not found earlier by other observers.

The first point leads to an increase in the number of objects, the others reduce it.

(1) *Completeness problem*. We must distinguish between catalogued (published) and uncatalogued (unpublished) objects. In total, the three Herschel catalogues contain 2500 entries (1000 in the first and second, 500 in the third). We have already seen that there are objects, which were not entered in any catalogue; many of them were called ‘suspected’ by Herschel. The total number is 76 (Table 5-5). 13 objects were found with the 7-ft (12 of them in the period of the star reviews; see Table 1-18). During the sweeps with the 20-ft, 59 were discovered; three were found with the 40-ft. Adding the 75 uncatalogued objects we get a total number of 2575.

Object	Date	Sw	Tel	Con	V	Type	ID	Remarks
NGC 6530	24 Aug. 1780	-	7-ft	Sgr	4.6	OC	S	Hodierna 1654
NGC 6535	24 Aug. 1780	-	7-ft	Ser	9.3	GC	S	
NGC 1981	23 Oct. 1780	-	7-ft	Ori	4.2	OC	S	
IC 4665	15 Jul. 1781	-	7-ft	Oph	4.2	OC	S	2 observations, de Chéseaux 1745
NGC 6838	4 Nov. 1782	-	7-ft	Sge	8.4	GC	SP	M 71, de Chéseaux 1745
Tr 7	4 Mar. 1783	-	7-ft	CMa	7.9	OC	S	
NGC 1904	4 Mar. 1783	-	7-ft	Lep	7.7	GC	SP	M 79, Méchain 1780
NGC 6871	23 Sep. 1783	-	7-ft	Cyg	5.2	OC	S	
NGC 2319	18 Dec. 1783	48	20-ft	Mon		*Grp	SC	VIII 1B (12)
NGC 3853	30 Dec. 1783	72	20-ft	Leo	12.4	Gx	S	
NGC 6819	14 May 1784	-	7-ft	Cyg	7.3	OC	S	3 observations
NGC 6625	15 Jul. 1784	238	20-ft	Sct	9.0	OC	S	
NGC 7770	18 Sep. 1784	277	20-ft	Peg	13.8	Gx	S	
NGC 7618	6 Oct. 1784	283	20-ft	And	13.0	Gx	S	
NGC 7810	17 Nov. 1784	320	20-ft	Peg	13.0	Gx	SC	H.MS., III 984; in *Zone Catalogue*
NGC 4039	7 Feb. 1785	368	20-ft	Crv	10.3	Gx	SC	IV 28.2, part of The Antennae
MCG -3-25-18	10 Mar. 1785	382	20-ft	Hya	13.3	Gx	S	
IC 780	6 Apr. 1785	393	20-ft	Com	12.9	Gx	S	
MCG 5-29-24	11 Apr. 1785	396	20-ft	Com	15.1	Gx	S	
NGC 4060	27 Apr. 1785	403	20-ft	Com	14.7	Gx	S	
NGC 4069	27 Apr. 1785	403	20-ft	Com	15.2	Gx	S	
NGC 4072	27 Apr. 1785	403	20-ft	Com	14.8	Gx	S	
NGC 967	6 Oct. 1785	459	20-ft	Cet	12.5	Gx	S	
NGC 17	27 Nov. 1785	478	20-ft	Cet	14.4	Gx	S	
MCG -2-6-52	27 Nov. 1785	478	20-ft	Cet	13.6	Gx	S	
NGC 4466	28 Dec. 1785	498	20-ft	Vir	13.5	Gx	S	
MCG -3-5-7	30 Dec. 1785	499	20-ft	Cet	13.4	Gx	S	
NGC 1038	1 Jan. 1786	505	20-ft	Cet	13.4	Gx	S	
MCG -1-35-7	4 Feb. 1786	522	20-ft	Vir	12.9	Gx	S	
IC 4996	20 Sep. 1786	594	20-ft	Cyg	7.3	OC	S	
NGC 7063	21 Sep. 1786	598	20-ft	Cyg	7.0	OC	S	
NGC 1128	30 Sep. 1786	607	20-ft	Cet	14.5	Gx	S	

Object	Date	Sw	Tel	Con	V	Type	ID	Remarks
King 17	18 Oct. 1786	619	20-ft	Aur	14.0	OC	S	
UGC 2272	26 Oct. 1786	626	20-ft	Aqr	13.8	Gx	S	
NGC 1449	26 Nov. 1786	638	20-ft	Eri	13.4	Gx	S	
NGC 1451	26 Nov. 1786	638	20-ft	Eri	13.4	Gx	S	
NGC 1603	28 Nov. 1786	638	20-ft	Eri	13.8	Gx	S	
IC 257	11 Dec. 1786	645	20-ft	Per	12.6	Gx	S	
NGC 204	21 Dec. 1786	657	20-ft	Psc	12.9	Gx	S	
Cr 115	26 Dec. 1786	667	20-ft	Mon	9.2	OC	S	
NGC 3910	27 Dec. 1786	671	20-ft	Leo	12.8	Gx	S	
NGC 769	11 Jan. 1787	680	20-ft	Tri	12.9	Gx	S	
NGC 3419	14 Jan. 1787	691	20-ft	Leo	12.5	Gx	S	
MCG -1-24-1	7 Mar. 1787	707	20-ft	Hya	11.3	Gx	S	
MCG 7-32-44	18 Mar. 1787	718	20-ft	Boo	14.2	Gx	S	
IC 944	19 Mar. 1787	720	20-ft	Boo	13.4	Gx	S	
IC 946	19 Mar. 1787	720	20-ft	Boo	13.4	Gx	S	
UGC 8902	19 Mar. 1787	720	20-ft	Boo	13.8	Gx	S	
UGC 8756	9 Apr. 1787	725	20-ft	CVn	13.6	Gx	SC	
NGC 5035	7 May 1787	732	20-ft	Vir	12.8	Gx	S	
UGC 9598	11 May 1787	733	20-ft	Boo	14.1	Gx	S	
NGC 5755	16 May 1787	738	20-ft	Boo	13.5	Gx	S	
NGC 6649	10 Jul. 1787	748	20-ft	Sct	8.9	OC	S	
LBN 537	3 Nov. 1787	773	20-ft	Cep	12.0	EN	S	
NGC 5981	25 May 1788	843	20-ft	Dra	13.0	Gx	S	extremely flat; Figure 2-185
UGC 3580	3 Dec. 1788	889	20-ft	Cam	11.8	Gx	S	
NGC 7441	28 Aug. 1789	-	40-ft	Aqr	13.8	Gx	S	Figure 2-174
UGC 3696	28 Dec. 1790	990	20-ft	Lyn	12.8	Gx	S	
NGC 4646	2 Apr. 1791	1001	20-ft	UMa	13.4	Gx	GC	II 794,2 = II 910
NGC 4695	2 Apr. 1791	1001	20-ft	UMa	13.5	Gx	S	"II 796" = III 985
IC 1339	29 Sep. 1791	-	40-ft	Cap	13.2	Gx	S	Figure 2-174
MCG 10-16-61	8 Apr. 1793	1038	20-ft	UMa	14.2	Gx	S	Figure 2-194
NGC 4831	9 Apr. 1793	-	40-ft	Hya	12.5	Gx	S	Figure 2-174
UGC 5722	9 Apr. 1793	1039	20-ft	UMa	14.6	Gx	S	
NGC 5519	12 May 1793	1043	20-ft	Boo	13.1	Gx	S	
NGC 5575	12 May 1793	1043	20-ft	Vir	13.3	Gx	S	
IC 4470	20 Dec. 1797	1074	20-ft	UMi	14.4	Gx	S	
NGC 3215	5 Apr. 1801	1097	20-ft	Dra	13.1	Gx	CC	2 obs., HON 8, III 981 (2503)
UGC 6728	5 Apr. 1801	1097	20-ft	Cam	13.7	Gx	S	
NGC 3210	26 Sep. 1802	1111	20-ft	Dra	14.2	*	CC	HON 6, III 979 (2501)
NGC 3212	26 Sep. 1802	1111	20-ft	Dra	13.2	Gx	CC	HON 7, III 980 (2502)
NGC 2629	30 Sep. 1802	1112	20-ft	UMa	12.2	Gx	CC	HON 1, III 982 (2504)
NGC 2641	30 Sep. 1802	1112	20-ft	UMa	13.6	Gx	CC	HON 2, III 983 (2505)
NGC 2650	30 Sep. 1802	1112	20-ft	UMa	13.3	Gx	CC	HON 3, II 908 (2506)
NGC 3034	30 Sep. 1802	1112	20-ft	UMa	8.4	Gx	CC	M 82, HON 4, Bode 1774, IV 79
NGC 3063	30 Sep. 1802	1112	20-ft	UMa		NF	CC	HON 5, II 909 (2508)

Table 5-5: Before or during the sweeps, Herschel discovered 76 objects, which were not catalogued (sorted by date).1035

Column 'ID' of the table shows the authority (by the published source), who detected an uncatalogued object in the documents: John Herschel's *Slough Catalogue* (SC), *Cape Catalogue* (CC) and *General Catalogue* (GC), Dreyer's *Scientific Papers* (SP) and the author's investigation (S). The number in brackets under 'Remarks'

is Caroline's 'General number' (GN), assigned to the eight objects of sweeps 1111 and 1112. The star group NGC 2319 and the single star NGC 3210 are listed because John has mentioned them. The present author has omitted all cases pointing to objects of stellar character. Actually, there are a few 'patches', identified as star patterns (asterism). In such cases, Herschel assumed nebulosity about the stars, which was an illusion. Examples are a 1.7' long chain of 13th mag stars in Canes Venatici and a similar one in Aquila, found in sweeps 405 and 426 on 2 May and 12 August 1785, respectively (see Figure 2-94). Of course, Dreyer had noticed the uncatalogued objects, hidden in the sweep records. Since they had not been checked during John's Slough observations, there was no confirmation. As a result, William's 'suspicious' objects were not entered into the NGC. But why does the table contain 47 NGC and eight IC objects? The answer is simple: they were rediscovered by other observers (mainly after William Herschel).

(2) *Identity problem*. Obviously, there are no identities among the uncatalogued objects. This is different in the published catalogues. Therefore, one should speak of 'entries' rather than 'objects'. Actually, there are up to four entries, referring to a single object.

A careful analysis of the catalogue data revealed that the 2500 entries belong to 2441 individual objects:

- in 51 cases two entries refer to a single object,
- in two cases three entries refer to a single object,
- in one case four entries refer to a single object.

What's behind the cases with three or four identical objects? The latter concerns Herschel's observation of M 20, the Trifid Nebula in Sagittarius (see section 2.2.6). On 12 June 1784 (sweep 236), unaware that he was seeing the Messier object, he found three bright 'large nebulae' close together; the trio is entered as V 10–12 in the first catalogue. Actually, they form the celebrated 'trifid' structure of M 20, later described by John. On 26 May 1786 (sweep 566), William found IV 41 near the determined place (it is listed in the second catalogue). The identity was not recognised. Of course, this is a limiting case, because the three 'large nebulae' (class V) are only parts of M 20.

The first case with three entries concerns the 11.4 mag galaxy NGC 4119 in Virgo (see Table 2-17). On 18 January 1784 (sweep 85), Herschel discovered II 14; about two months later, on 15 March (sweep 174), he saw II 60 and finally on 14 April (sweep 194) the 'bright nebula' I 33. All three were entered in the first catalogue. Caroline has written in the *Zone Catalogue*: "II. 60 and I. 33 were seen in two different sweeps, their AR and PD are nearly the same; but description differs." John could only see I 33 (h 1094). Her remark probably let him identify the two nebulae in the *General Catalogue*. Dreyer followed this view and set NGC 4124 = I 33 = II 60 = h 1094 = GC 2734. For the sake of completeness, John catalogued II 14 as GC 2730 and Dreyer agreed again, creating NGC 4119. None of these authorities saw an identity with the former numbers.

In the second case, Herschel catalogued the 9.3 mag galaxy NGC 4526 in Virgo three times, as I 31, I 38 and I 119, found in sweeps 191, 202 and 498, respectively (the dates are 13 & 18 April 1784 and 28 December 1785). I 31 and I 38 were entered in the first catalogue, I 119 in the second.

C1	H1	Sw1	Date1	NGC1	C2	H2	Sw2	Date2	NGC2	Con	V	T	Remarks
1	**VIII 5**	81	18 Jan. 1784	2264	2	**V 27**	494	26 Dec.1785	2264	Mon	4.1	OC	Christmas Tree Cluster
1	**III 5**	83	18 Jan. 1784	3342	3	**I 272**	-	4 Mar. 1796	3332	Leo	12.3	Gx	front-view, Uranus
1	**III 6**	87	18 Jan. 1784	4698	1	**I 8**	106	23 Jan. 1784	4698	Vir	10.6	Gx	near M 49
1	**I 11**	146	15 Feb. 1784	4153	1	**I 19**	170	14 Mar. 1784	4147	Com	10.4	GC	Figure 2-39
1	**IV 6**	157	23 Feb. 1784	3423	1	**II 131**	191	13 Apr. 1784	3423	Sex	11.1	Gx	
1	**VI 6**	161	8 Mar. 1784	2355	1	**VII 6**	176	16 Mar. 1784	2356	Gem	9.7	OC	
1	**VI 8**	209	25 April 1784	5634	1	**I 70**	380	5 Mar. 1785	5634	Vir	9.5	GC	

Table 5-6: Identical objects with significant class difference in the three catalogues. I 272 was found near Uranus by the front-view (see Table 2-17). Note that the NGC-numbers are not always identical.

Of the 51 two-entry cases, we treat those with a significant class difference (Table 5-6). In 38 cases the identity is due to John Herschel and Dreyer.1036 In the first, William found the 15 Mon cluster (VIII 5) in sweep 81. In sweep 494, he perceived a nebula (V 27) surrounding the star. Cluster and nebula were combined in sweep 682 (11 January 1787), though not clearly identified: "15 Monocerotis; surrounded by many brilliant stars. I suspect the sp 2 stars, (of which one is a Double) to be affected with very faint milky nebulosity but may be a deception." The sixth case was first seen

"pretty much compressed" (VI 6) and later as a "close cluster of stars".1037

(3) *Type problem*. Herschel mainly discovered true non-stellar objects: galaxies, galactic nebulae and star clusters.1038 Although not intended by him, the three catalogues also contain unwanted things, like single stars, pairs or star groups.1039 There are even entries, which do not refer to any object; this case may be called 'non-existent' or, more carefully, 'not found' (the latter term is used here).1040

Table 5-7 defines the object categories and modern types, contained in the Herschel catalogues. Table 5-8 gives the relation of modern types with Herschel's eight classes I–VIII (compare Table 2-39 for the values of the first catalogue).

Category	**Sub-category**	**Modern type** (Abbreviation)	**Cat I**	**Cat II**	**Cat III**	*Sum*
non-stellar object	nebula	**galaxy** (Gx)	825	842	440	**2107**
		emission/reflection nebula (EN, RN)	16	12	7	**35**
		planetary Nebula (PN)	11	17	6	**34**
	star cluster	**open cluster** (OC)	54	82	25	**161**
		globular cluster (GC)	27	9	2	**38**
other	part of an object	galaxy part (GxP)	3	3	3	**9**
	star	single (*)	4	1	2	**7**
		pair/multiple (*2, *3 etc.)	7	4	2	**13**
		group/asterism (*Grp)	13	11	2	**26**
	non-existent?	not found (NF)	8	3	0	**11**
		Sum	**968**	**984**	**489**	**2441**

Table 5-7: Content of the three Herschel catalogues; galaxies clearly dominate.

Modern type (Abbreviation)	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	*Sum*
galaxy (Gx)	262	882	942	38	30	2			**2155**
emission/reflection nebula (EN, RN)	3	3	3	16	13				**38**
planetary Nebula (PN)	3	5	5	20	1	1			**35**
open cluster (OC)		1	2		2	28	62	70	**165**
globular cluster (GC)	17	10	2	2		9			**40**
galaxy part (GxP)	3		5		1				**9**
stars (single, pair, group)		4	14	2		2	5	18	**45**
not found (NF)		2	5		5				**12**
Sum	**288**	**907**	**978**	**78**	**52**	**42**	**67**	**88**	**2500**

Table 5-8: Modern object types vs. Herschel's eight classes.

Among the 75 uncatalogued objects, 73 are non-stellar: 57 galaxies, 11 open clusters, three globular clusters and one emission nebula. The rest are: one star, one star group and one 'object' with status

‘not found’.

(4) *Discovery problem*. The last point refers to the fact that some objects were discovered earlier by other observers. This leads to a reduction in the number of objects, which can be credited to Herschel. When he started, the main sources are the deep-sky catalogues of Bode (1777) and Messier (1781); neither were known to him at that time.

Table 5-9 shows all 33 objects, discovered earlier by other observers. In most cases, Herschel was not aware of this fact; they are called ‘independent’ discoveries. 10 objects are due to Méchain, seven to Caroline, five each to Hodierna and Messier, two to Hipparchus and one each to de Chéseaux, Flamsteed, Mairan and Oriani. 11 of the 33 objects are contained in the *Messier Catalogue*.

The seven added M-objects (M 104–110) were completely unknown to William. All were independently found by him; however, M 110 was seen even earlier by Caroline. Looking at his 75 uncatalogued objects of Table 5-5, we see that five cannot be credited to him: M 71, M 79, M 82, NGC 6530 and IC 4665. Remember that M 82 was not identified on 30 September 1802 (sweep 1112), whereas in the four other observations, the identification was correct (see section 3.3.3).

M	H	C	NGC	Sw	Date	Discoverer	Date	Con	V	Type	Remarks
	V 1	1	253	8	30 Oct. 1783	C. Herschel	23 Sep. 1783	Scl	7.2	Gx	Sculptor Galaxy
	III 1	1		15	3 Nov. 1783	Mairan	1731	Ori		EN	in M 42
49	I 7	1	4472	105	23 Jan. 1784	Messier	19 Feb. 1771	Vir	8.4	Gx	
	VII 2	1	2244	114	24 Jan. 1784	Flamsteed	17 Feb. 1690	Mon	4.8	OC	
105	I 17	1	3379	164	11 Mar. 1784	Méchain	24 Mar. 1781	Leo	9.3	Gx	
95	I 26	1	3351	177	19 Mar. 1784	Méchain	20 Mar. 1781	Leo	9.7	Gx	
91	II 120	1	4548	187	8 Apr. 1784	Messier	18 Mar. 1781	Com	10.2	Gx	
104	I 43	1	4594	210	9 May 1784	Méchain	11 May 1781	Vir	8.0	Gx	Sombrero Galaxy
8	V 13	1	6533	223	22 May 1784	Hodierna	1654	Sgr	5.8	EN	Lagoon Nebula
20	V 10	1	6514	236	12 Jul 1784	Messier	5 Jun. 1764	Sgr	8.5	EN+OC	Trifid Nebula
33	V 17	1	598	266	11 Sep. 1784	Hodierna	1654	Tri	5.7	Gx	Triangulum Nebula
110	V 18	1	205	282	5 Oct. 1784	Messier	10 Aug. 1773	And	8.1	Gx	
	VII 12	1	2360	366	4 Feb. 1785	C. Herschel	26 Feb. 1783	CMa	7.2	OC	
47	VIII 38	1	2422	366	4 Feb. 1785	Hodierna	1654	Pup	4.4	OC	
	VII 17	1	2362	381	6 Mar. 1785	Hodierna	1654	CMa	3.8	OC	
48	VI 22	2	2548	519	1 Feb. 1786	Messier	19 Feb. 1771	Hya	5.8	OC	
61	I 139	2	4303	553	17 Apr. 1786	Oriani	5 Mai 1779	Vir	9.7	Gx	
	VII 32	2	752	599	21 Sep. 1786	Hodierna	1654	And	5.7	OC	
	VIII 60	2	2311	639	26 Nov. 1786	C. Herschel	4 Mar. 1783	Mon	9.6	OC	
	I 186	2	5195	734	12 May 1787	Méchain	21 Mar. 1781	CVn	9.6	Gx	
	VI 30	2	7789	769	18 Oct. 1787	C. Herschel	30 Oct 1783	Cas	6.7	OC	
76	I 193	2	651	780	12 Nov. 1787	Méchain	5 Sep. 1780	Per	10.1	PN	Little Dumbbell
106	V 43	2	4258	816	9 Mar. 1788	Méchain	Jul.1781	CVn	8.4	Gx	
102	I 215	2	5866	842	5 May 1788	Méchain	27 Mar. 1781	Dra	9.9	Gx	
	VIII 72	2	6633	850	30 Jul 1788	de Chéseaux	1745	Oph	4.6	OC	
	VIII 77	2	7380	876	1 Nov. 1788	C. Herschel	7 Aug. 1787	Cep	7.2	OC	
	VI 33	2	869	877	1 Nov. 1788	Hipparchus	130 B.C.	Per	5.3	OC	Double Cluster
	VI 34	2	884	877	1 Nov. 1788	Hipparchus	130 B.C.	Per	6.1	OC	Double Cluster
	VIII 78	2	225	887	26 Nov. 1788	C. Herschel	27 Sep. 1783	Cas	7.0	OC	
109	IV 61	3	3992	919	12 Apr. 1789	Méchain	12 Mar. 1781	UMa	9.8	Gx	
108	V 46	3	3556	922	17 Apr. 1789	Méchain	16 Feb. 1781	UMa	10.0	Gx	
	VII 59	3	6866	959	11 Sep. 1790	C. Herschel	23 Jul. 1783	Cyg	7.6	OC	
107	VI 40	3	6171	1043	12 May 1793	Méchain	Apr. 1782	Oph	7.8	GC	

Table 5-9: These 33 objects, observed and catalogued by Herschel, were actually discovered earlier by other observers.

Table 5-10 shows the result of a careful examining of the four *problems*, giving the final number of individual non-stellar objects, discovered by Herschel: 2409.

Objects / point	(1a) catalogued	(1b) uncatalogued	Sum
all objects	2500	75	2575
(2) double or multiple entries	-59	0	-59
individual objects	2441	75	2516
(3) object part, star(s), not found	-66	-3	-69
individual non-stellar objects	2375	72	2447
(4) earlier discoverers	-33	-5	-38
Herschel's individual non-stellar objects	2342	67	**2409**

Table 5-10: Number of objects and their reductions due to the *problems* (1) to (4) treated above. This leads to the net result of 2409 discoveries.

In Section 5.1.2, where Herschel's success rate of finding non-stellar

objects was determined, we have already mentioned the number of objects, missed by him in the sweeps due to the fact that the path leaves gaps. The number is based on a list of targets, compiled by the following criteria:

- non-stellar object in NGC/IC,
- not observed by Herschel,
- later visually discovered by another observer,
- located in a sweep,
- bright enough to be visible in Herschel's 18.7-inch reflector (limit set to 13.5 mag).

The analysis yields a number of 1076 missed non-stellar objects: 980 galaxies, 67 emission/reflection nebulae, 17 planetary nebulae, 8 globular clusters, 4 open clusters. Most objects (246) were later found by John; 153 are due to Swift, 117 to Stephan, 106 to Marth and 102 to d'Arrest. 28 objects were seen at Birr Castle. The brightest is the open cluster NGC 1981 in Orion (4.2 mag), found by John on 4 January 1827 at Slough.

Star	Con	V*	D (')	NGC	V	Sweeps	Remarks
409 Cet (B)	Cet	7.1	0.8	988	11.0	355	star superimposed
U^{27}	Vir	7.7	1.5	4269	12.9	131	pair with IC 3155
U^{398}	And	6.4	4.0	169	12.4	328	pair with IC 1559
θ Crt	Crt	4.8	4.4	3763	11.8	537, 705, 825	
16 Psc	Psc	5.6	4.9	7714	12.5	461	JH, pair with NGC 7715 (edge-on)
31 Leo	Leo	4.5	4.9	3130	13.4	83	JH
3 Quad. Mur. (B)	Boo	5.6	6.8	5794	13.5	736	JH, trio with NGC 5797/5804 (III 678/79)
o Per	Per	3.9	7.7	IC 348	7.3	905, 980	OC+RN (Ced 21)
U^{243}	Ari	7.6	8.0	765	12.8	264	
$υ^1$ Cnc	Cnc	5.7	8.6	IC 509	13.0	323, 703	
ν Eri	Eri	4.1	10.4	1622	12.5	634, 640	in 18' long chain with NGC 1618/25
ε And	And	4.5	11.6	183	12.7	266	trio with NGC 181/84
5 Her	Her	5.2	11.7	6030	12.8	171, 183, 573, 723	
212 Vir (B)	Vir	6.9	11.8	4518	13.8	202	JH
$ξ^1$ Vir	Vir	5.0	12.1	3863	12.9	194	elongated
18 Boo	Boo	5.3	13.2	5550	13.2	189	JH
U^{938}	Dra	6.7	14.0	4221	12.5	954	JH
69 Peg	Peg	5.8	14.7	7664	12.7	264	

Table 5-11: There are 18 missed non-stellar objects within 15' of stars, observed by Herschel in the sweeps. The objects are sorted by increasing distance (D); except IC 348, all objects are galaxies. (B) refers to Bode's catalogue; U = 'unknown star'; V* = star magnitude; JH = object found by John. The mentioned components in 'Remarks' are fainter.

To extract the most promising targets, Caroline's list of all stars, observed in the sweeps, can be used. Now it is possible to determine those non-stellar objects, nearest to one of these stars. Table 5-11 gives the distances up to 15' (diameter of the standard field of view). There are 18 cases.

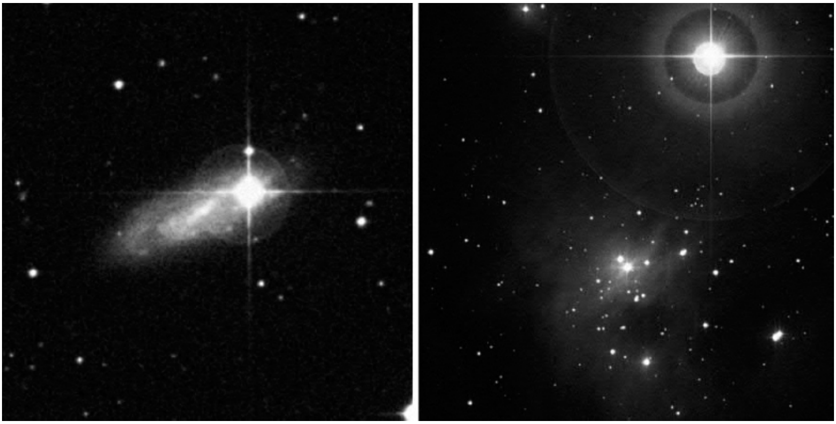


Figure 5-14: Objects, missed by Herschel. Left: NGC 988 in Cetus, superimposed by a 7.1 mag star. Right: the open cluster IC 348, south of o Per, imbedded in the faint reflection nebula Ced 21.

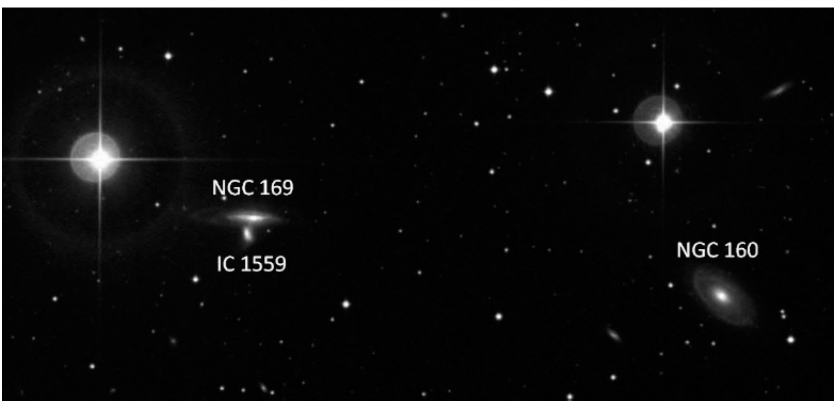


Figure 5-15: NGC 160 in Andromeda was discovered by Herschel, but not NGC 169. The bright stars were both seen, though in different sweeps.[1041]

The most remarkable case is NGC 988 in Cetus, where the 7.1 mag star is superimposed on the 11.0 mag spiral galaxy (Figure 5-14,

left). It was found by on 29 November 1875 by Stephan with a 31-inch reflector. It is a miracle, why Herschel did not mention the object. In sweep 355 (10 January 1785), we only read about a 7 to 8 mag star. Unfortunately, there was no second observation. But, as we see in five cases, later sweeps brought no better result. In the case of ο Per, Herschel missed the open cluster IC 348, only 8' south, imbedded in the faint nebulosity Ced 21 (Figure 5-14, right). The small cluster (diameter 10') was found by Safford on 1 December 1866 with an 18.6-inch refractor. Another remarkable case is NGC 169 in Andromeda, 4' southwest of the 6.4 mag star U^{398} (HD 3411), not observed by Flamsteed. The companion, IC 1559 (14.0 mag) is only 24" south. In sweep 328 (4 December 1784), the star was seen, but not the galaxy – "a very thin whitish haziness all over" may explain this. The curiosity: only 13' west is a similar star/galaxy pair, made of a 7.2 mag star (HD 3293) and NGC 160 (12.7 mag), located 4.2' south. In sweep 484 (5 December 1785), the galaxy was found: "very faint, very small, stellar, a few minutes of a pretty bright star, 240 shewed the same". The star was not listed by Caroline. The ensemble is seen in Figure 5-15. The case of the NGC 1618/22/25 chain near ν Eri is treated in section 2.5.1.

5.2.3. Brightness, size, multiple objects and constellations

The mean object magnitude in the three Herschel catalogues is 12.0 mag (Figure 5-16). The individual values for the parts are 11.9 mag, 12.5 mag and 11.2 mag (the second catalogue shows the lowest value).

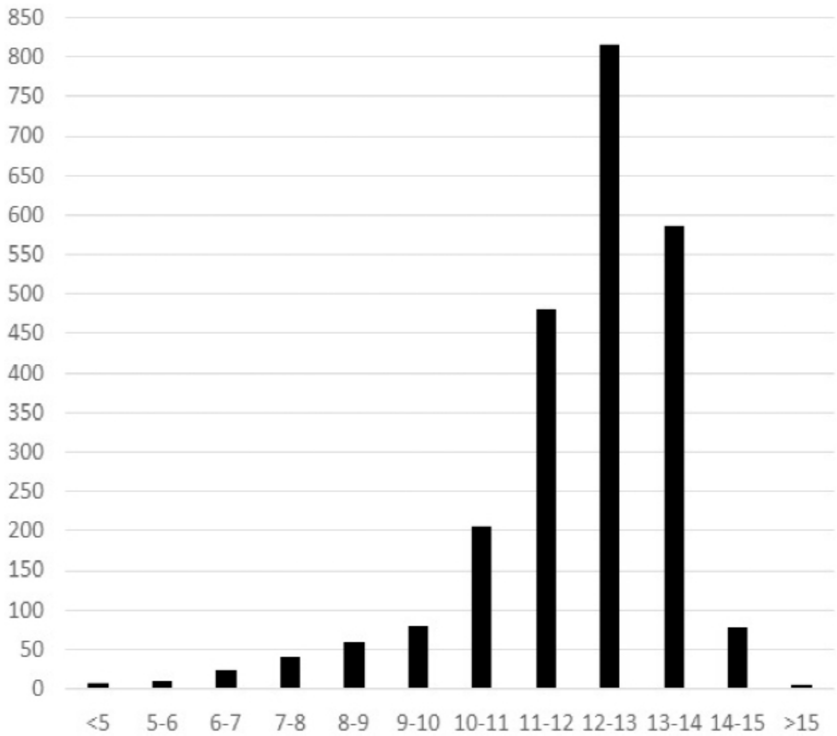


Figure 5-16: Brightness distribution for the 2375 individual non-stellar objects in the three catalogues (mean = 12.0 mag).

The brightest object is the 3.8 mag open cluster NGC 2362 (VII 17) in Canis Major (Figure 5-17). This is the compact ensemble around the dominant 4.4 mag star τ CMa. The faintest object is the 15.5 mag galaxy NGC 2843 (III 64) in Cancer (see Figure 2-50). Table 5-12 gives the brightest and faintest exemplar for the relevant object types, found by Herschel.[1042] However, the catalogue contains single stars too (thought to be 'nebulous'). The brightest is NGC 1990 (V 34) = ε Orionis with 1.4 mag, the faintest is NGC 4879 (III 759) in Virgo with 15.5 mag.

Type	V	H	NGC	Con	Remarks
Gx	8.5	V 44	2403	UMa	
	15.5	III 64	2843	Cnc	Figure 2-50
EN	5.0	V 37	7000	Cyg	North America Nebula; Figure 2-131
	8.5	IV 41	6514	Sgr	M 20, Trifid Nebula; Figure 2-76
PN	7.7	IV 27	3242	Hya	Ghost of Jupiter
	13.5	III 936	7076	Cep	
OC	3.8	VII 17	2362	CMa	around τ CMa; Figure 5-17
	14.5	VIII 7	1663	Ori	
GC	7.4	I 44	6401	Oph	
	11.2	III 558	7492	Aqr	

Table 5-12: Brightest and faintest non-stellar object, found by Herschel, for the relevant types.

Figure 5-17: The open cluster NGC 2362 in Canis Major is the brightest Herschel object; it is dominated by the 4.4 mag star τ

CMa.

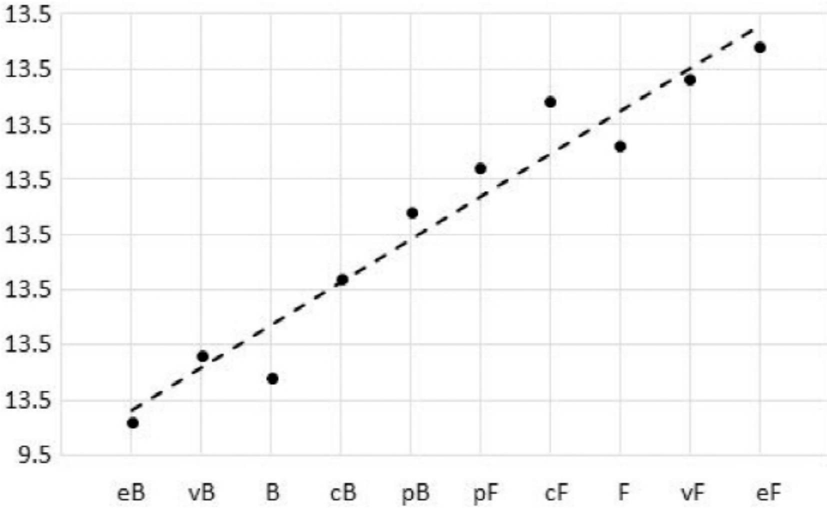


Figure 5-18: Relation between Herschel's 'brightness class' and modern magnitude.

Herschel gives no magnitudes, but only an estimated 'brightness class', ranging from 'extremely bright' (eB) to 'extremely faint' (eF); the NGC even used 'eeeF'. To see, how these classes correspond to modern magnitudes, the mean, minimum and maximum values and the related objects are given in Table 5-13; Figure 5-18 shows a fairly good correlation.

BC	V_{mean}	V_{max}	Cat	H	NGC	Con	Type	V_{min}	Cat	H	NGC	Con	Type
eB	9.8	8.9	2	I 163	3115	Sex	Gx	10.3	2	I 126	5746	Vir	Gx
vB	10.4	8.0	1	IV 1	7009	Aqr	PN	13.0	2	I 179	IC 3668	CVn	GxP
B	10.2	7.7	1	IV 27	3242	Hya	PN	12.0	1	I 37	4551	Vir	Gx
cB	11.1	7.2	1	V 1	253	Scl	Gx	13.2	1	III 198	946	And	Gx
pB	11.7	7.1	1	IV 22	2467	Pup	EN	14.3	3	II 795	4675	UMa	Gx
pF	12.1	9.3	1	II 198	6540	Sgr	GC	13.5	3	II 810	6130	Dra	Gx
cF	12.7	8.8	3	IV 76	6946	Cyg	Gx	14.8	3	III 817	4834	CVn	Gx
F	12.3	8.3	1	IV 12	6553	Sgr	GC	14.8	1	II 242	7681	Peg	Gx
vF	12.9	9.5	3	V 50	2997	Ant	Gx	15.0	3	III 812	6088	Dra	Gx
eF	13.2	10.2	2	V 29	4395	CVn	Gx	15.5	1	III 64	2843	Cnc	Gx

Table 5-13: Herschel's estimated brightness classes (BC) vs. modern magnitude values (V_{mean}). The objects, corresponding to the extreme values (V_{max}, V_{min}) in each class, are presented.

Herschel also coded the object size, from 'very large' (vL) to 'very

small' (vS). Sometimes the description also gives the size (length, breadth) in arcminutes. He estimated it by the diameter of the standard field (15'). It is interesting to analyse the class V objects ('large nebulae'). Does 'large' mean >15'? To answer this question, it is useful to compare the size values from the descriptions to modern values (maximum diameter).

Table 5-14 lists 18 cases, where Herschel's size is realistic. Some objects were observed in different sweeps; then the size values differ depending on the observing conditions. The two largest objects are among Herschel's 52 'extensive diffused nebulosities' (see section 4.2.1): the North America Nebula NGC 7000 (V 37), represented by the regions no. 44 and 46, and the Veil Nebula NGC 6992 (V 14); the latter is not among the numbered cases. Both objects are in Cygnus; NGC 7000 is 12° north of NGC 6992.

H	Size (')	WH (')	NGC	Con	V	Type	Obs	Remarks
V 19	12	15	891	And	9.9	Gx	3	edge-on, dark lane
V 8	13	8–20	3628	Leo	9.5	Gx	4	
V 29	13	12	4395	CVn	10.2	Gx	1	
V 42	15	16	4631	CVn	9.2	Gx	1	
V 24	16	20	4565	Com	9.6	Gx	1	edge-on, dark lane
V 41	17	18–20	4244	CVn	10.4	Gx	1	extremely flat
V 43	19	10–15	4258	CVn	8.4	Gx	3	M 106
V 20	19	26	247	Cet	9.1	Gx	1	
V 18	20	20–30	205	And	8.1	Gx	4	M 110
V 51	22	25	4236	Dra	9.6	Gx	2	Figure 2-192
V 44	23	6–30	2403	Cam	8.5	Gx	2	
V 1	29	20–50	253	Scl	7.2	Gx	4	Sculptor Galaxy
V 28	30	12	2024	Ori		EN	2	Flame Nebula
V 13	45	16	6533	Sgr	5.8	EN	2	M 8, Lagoon Nebula
V 17	69	18–30	598	Tri	5.7	Gx	3	M 33, Triangulum Nebula
V 14	60	45	6992	Cyg		EN	2	Veil Nebula (east)
V 15	70	44–63	6960	Cyg		EN	2	Veil Nebula (west)
V 37	120	105	7000	Cyg	5.0	EN	2	North America Nebula

Table 5-14: Class V objects with realistic sizes (WH). 'Obs' = number of observations.

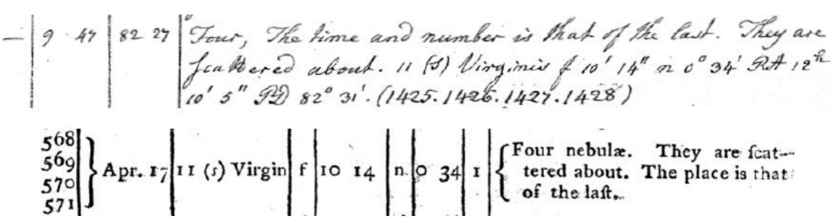
Table 5-15 gives class V objects with unrealistic sizes.[1043] V 3 (NGC 4910) in Virgo is curious; there is no 'very large' nebula at the place (status 'not found'). V 16 in Andromeda is actually a small group of galaxies around NGC 68. The nebula V 49 (NGC 1624) in Perseus

was found in sweep 989 (28 December 1790): "6 or 7 small stars with faint nebulosity between them, of considerable extend." This explains the classification.

H	Size (')	WH (')	Descr.	NGC	Con	V	Type	Obs	Remarks
V 3	-		vL, vF stars	4910	Vir	-	NF	1	sketch
V 16	1.2 × 1.1	5–6		68	And	12.9	Gx group	1	+ NGC 70–72
V 6	1.8 × 1.5		vL	5293	Boo	13.1	Gx	1	
V 7	2.7 × 2.6		vL	3346	Leo	11.7	Gx	1	
V 40	2.9 × 2.4	7	mE	3513	Crt	11.5	Gx	2	pair with V 39
V 49	3.0		cL	1624	Per	11.8	OC+EN	1	
V 23	3.9 × 1.4	4–7	L, lE	3027	UMa	11.8	Gx	2	
V 25	4.1		pL	246	Cet	10.9	PN	1	
V 36	4.2	20	vL, mE	206	And	14.0	GxP	3	
V 4	4.3 × 3.2	5–6	vL, E	4123	Vir	11.4	Gx	2	sketch
V 32	5.0 × 3.0		vL	1788	Ori		RN	2	
V 26	5.7 × 1.4	2–8	mE	3003	LMi	11.9	Gx	2	
V 9	6.0 × 3.0		L, E	6526	Sgr		EN	1	in M 8
V 39	6.0 × 2.1	8	mE	3511	Crt	11.0	Gx	2	pair with V 40
V 45	6.9 × 3.6	6–8	E	3953	UMa	10.1	Gx	2	
V 51	7.2 × 3.0	25	mE	4236	Dra	9.6	Gx	2	
V 52	7.2 × 4.4	5	L, lE	3359	UMa	10.6	Gx	1	
V 2	7.6 × 3.2	8–10	vL, mE	4536	Vir	10.6	Gx	3	
V 47	8.1 × 1.3	8	mE	3079	UMa	10.9	Gx	1	
V 22	8.2 × 1.0	4–6	mE	5170	Vir	11.1	Gx	2	extremely flat
V 46	8.6 × 2.4	10	mE	3556	UMa	10.0	Gx	2	M 108, sketch
V 50	8.9 × 6.8	8	vL	2997	And	9.5	Gx	1	Figure 2-192
V 21	9.0 × 6.0		E	2359	CMa	11.5	EN	2	
V 48	9.4 × 6.6	8	E	1097	For	9.5	Gx	1	Figure 2-181

Table 5-15: Class V objects with unrealistic sizes (WH). 'Obs' = number of observations; objects sorted by size.

The Herschel catalogues feature multiple nebulae, indicated by combined entries, marked by a bracket (Figure 5-19). In most cases they were observed in a single field of view; then only one position is given (based on a single measured nebula).


— | 9 47 | 82 27 | Four, The time and number is that of the last. They are scattered about. 11 (s) Virginis f 10' 14" n 0° 34' RA 12h 10' 5" PD 82° 31'. (1425. 1426. 1427. 1428)

568 569 570 571 Apr. 17 | 11 (s) Virgin | f | 10 14 | n. | 0 34 | 1 | Four nebulæ. They are ſcattered about. The place is that of the laſt.

Figure 5-19: Multiple nebulae were given a common entry in the

sweep record (above); in the catalogue they are marked by a bracket (below). The quartet is GN 1425–28 = II 568–71 = NGC 4268/70/73/81 in Virgo; the galaxies were discovered on 17 April 1786 (sweep 553); see Figure 2-104.

Table 5-16 gives the number of cases. They are treated in 'Article 11' of the 1811 publication (see Table 4-6). The separation ranges from 0.5' to 15'. Herschel's closest pair is NGC 545/47 (II 448/49) in Cetus; the galaxies are both of 12.2 mag and belong to the galaxy cluster Abell 194 (Figure 2-101).

Category	Number	Objects (number)
double nebula	118	galaxy pair (109)
		galaxy + part (4)
		galaxy + star (3)
		star pair (1)
		double planetary (1)
triple nebula	13	galaxy trio (13)
quadruple nebula	5	galaxy quartet (4)
		nebula + parts (1)
sextuple nebula	1	galaxy sextet (1)

Table 5-16: Double and multiple objects (and their variation) in Herschel's catalogues; the is no quintuple nebula.

Special cases	Con.	Objects	Size (')	Remarks
galaxy + part	Tri	M 33 (V 17) + NGC 604 (III 150)	13.2	HII-region
	Leo	NGC 2903 (I 56) + NGC 2905 (I 57)	1.2	HII-region
	CVn	NGC 4656 (I 176) + NGC 4657 (I 177)	3.2	HII-region
	CVn	NGC 4618 (I 178) + IC 3668 (I 179)	8.8	HII-region
galaxy + star	Vir	NGC 5174 (III 45) + NGC 5175 (III 46)	2.3	* 12.6 mag (NE)
	Psc	NGC 421 (III 155) + NGC 420 (III 154)	10.0	* 12.9 mag (SW)
	Vir	NGC 4878 (III 758) + NGC 4879 (III 759)	4.4	* 15.5 mag
star pair	Psc	NGC 552 (III 172) + NGC 553 (III 175)	1.3	* 14.0/13.9 mag
double planetary	Gem	NGC 2371 (III 316) + NGC 2372 (III 317)	0.4	bipolar
galaxy quartet	Com	NGC 4169, 4173–75 (III 358, 372, 359, 360)	6.5	The Box, HCG 61
	Cet	NGC 833, 835, 838, 839 (II 482–85)	7.0	Arp 318
	Vir	NGC 4268, 4270, 4273, 4281 (III 568–71)	15.0	
	And	NGC 703, 704, 705, 708 (III 562–65)	5.0	Abell 262
nebula + parts	Sgr	M 20 (IV 41, V 10–12)	5.0	Trifid Nebula
galaxy sextet	Com	NGC 4061, 4065, 4066, 4070, 4074, 4076 (III 391–96)	15.0	

Table 5-17: Special object types. 'Size' means separation for pairs, otherwise the circle enclosing the multiple object.[1044]

Mainly, we have ordinary pairs or small groups of galaxies, but

there are also remarkable or even exotic cases (Table 5-17), like galaxy/star combinations.

We have already seen that there was a significant overlap between the sweep areas (Figure 5-9). This implies multiple observations of an object. Herschel's column 'Obs.' shows how many times an object was seen. However, the given numbers are restricted to the individual catalogue. There is no hint about observations made after closing the manuscript. Fortunately, this information is presented in Caroline's later compilations. The first is her 'Catalogue 2500 Nebulae and Clusters', giving the sweep numbers for each entry. The second, and more detailed source, is the *Zone Catalogue* (see section 6.1), listing every observation of an object and all relevant data (date, sweep, reference star, determined position). Given the amount of information, the number of errors is small. Only a few objects or observations are missing or incorrect. As always, Caroline has made a very good job.

Based on a modern analysis, 1603 catalogued objects were seen only once in a sweep, 673 twice, 160 three times, 46 four times, 9 five times, 5 six times and 1 even nine times (open cluster NGC 2420 in Gemini). Additional observations were often used to improve the object data or to clear identification problems. In 514 sweeps (of 1112), no non-stellar object was discovered; 215 sweeps brought only one object, 113 sweeps two and 62 sweeps three. The top scorers: 42 objects were found in sweep 405 and as many as 71 in the record sweep 396.

Constellations also is an interesting topic. It is not surprising that the maximum number of objects was found in Virgo (362); second best is Ursa Major (285). These are large regions with many galaxies. Only one object was discovered in Antlia, Centaurus, Equuleus and Lyra (Table 5-18, Figure 5-20). The latter is remarkable, because there are some good candidates. Alas, the prominent constellation was not sufficiently swept, as seen in Figure 5-6.[1045] No non-stellar object was found in Piscis Austrinus, though the southern constellation was visited in four sweeps.[1046] There are actually 24 objects (all galaxies) with a brightness between 11.0 and 13.6 mag; 16 of them were later found by John, using the 18¼-inch reflector at the Cape, having a much better view from there.

Constellation	Sw	Date	H	NGC	V	Remarks
Centaurus	711	15 Mar. 1787	II 638	5253	10.4	elongated, δ = -30.5°
Equuleus	973	10 Oct. 1790	III 858	7046	13.1	face-on
Antlia	1033	4 Mar.1793	V 50	2997	9.5	face-on, δ = -30.3°; Figure 2-192
Lyra	1109	26 Jun. 1802	II 907	6646	12.6	1.8° NW of Vega; star 8.8 mag 4' north

Table 5-18: In these four constellations, only one object was discovered (all are galaxies).

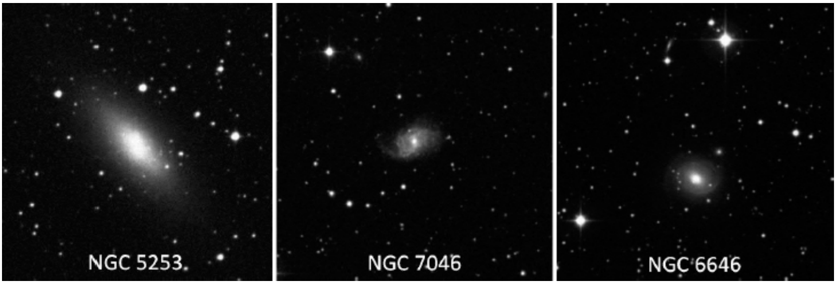


Figure 5-20: Three galaxies of Table 5-18; all seen with the front-view (images 7.5' × 7.5').

Constellation	Area (deg^2)	Objects	Objects/$arcmin^2$
Coma Berenices	386,475	164	1.53
Canes Venatici	465,194	145	1.12
Virgo	1,294,428	362	1.01
Ursa Major	1,279,660	285	0.80
Leo	946,964	166	0.63
Aquila	652,478	11	0.06
Equuleus	71,641	1	0.05
Scorpius	496,783	3	0.02
Capricornus	413,947	2	0.02
Lyra	286,476	1	0.01

Table 5-19: Herschel object numbers in constellations. Those with the five highest and lowest object densities are listed. As expected, Coma Berenices is the most crowded and Lyra the least crowded place.

Table 5-19 gives the object density in constellations. The five with the highest/lowest object densities are listed. Of course, being the centre of Herschel's 'nebular stratum', Coma Berenices dominates.

Due to its large size, Virgo is only third best (but leading in the absolute number). As mentioned, Lyra was not sufficiently swept.

5.2.4. Observing sites, viewing modes, moonlight and weather

Herschel swept at three different places, all located in the Windsor area (see Figure 2-3). He started in October 1783 at Datchet, where 413 sweeps were made; Clay Hall (Old Windsor) brought 137 and Slough 562.

Concerning the viewing direction, 975 sweeps were performed in the south meridian, 132 in the north (107 above the pole, 22 below) and five in the east. In the latter cases, the telescope was rotated in azimuth by the 'round motion'. This led to problems, like sweep 1096 impressively demonstrates (see section 3.3.2). The eastern sweep was primarily made to observe the Andromeda Nebula and its vicinity (see section 2.2.6). Up to September 1784, the telescope could not be elevated higher than about 73°, more was too dangerous. Thus M 31, not yet seen in the 20-ft, was too high in the south and Herschel decided to catch it at a lower altitude in the east.

Observing at higher elevations was first tried in December 1783. For this the bottom of the tube could be shifted on a bar towards the centre of the azimuthal ring (see Figure 2-7). This allowed a much steeper tube angle. The gallery was then about 5 m above the ground – a dangerous place for observing at the Newtonian focus. In April 1785, a bar table was introduced to quantify the shift at the bottom. However, it took until 15 March 1787 to exactly reach the zenith (PD 38.5°); now the tube end was set beyond the centre. The Newtonian configuration was used in 601 sweeps; 511 were made with the front-view. The latter design, installed in October 1786 and used until the very last observations, was much safer at high elevations. Moreover, the front-view showed fainter objects.

Observing was affected by Moon and weather. To examine these factors, it is useful to look at a homogenous sample: nights with sweeps. The records contain notes about moonlight or weather conditions. Some sweeps were delayed, interrupted or even

terminated by haze or clouds (the term 'half swept' was used). For the Herschels, that required a continuous inspection of the atmospheric conditions – and a permanent readiness.

Of course, there is a relation between lunar phase and observing frequency. However, it cannot be sufficiently derived from the few notes in the sweep records. A much better result is obtained from the examination of an entire observation year. The best candidate is 1784, when a record number of 128 nights were used for 275 sweeps. The total observing time for each night can be determined from the records. On the other hand, the daily lunar phase is taken from published tables, like that offered by the *U.S. Naval Observatory*. Both data can be combined. The analysis yields the expected correlation between phase and observing hours (Figure 5-21).

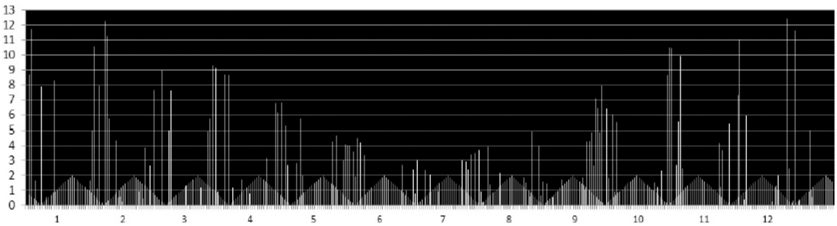


Figure 5-21: Phase of the Moon (lunation) and the daily observing time (0–13 hours) for the record year 1874 (months 1–12). As expected, the period around New Moon was often used, but there are exceptions.

The phase is symbolized by the bars forming a triangle, starting from New Moon to Full Moon and back to New Moon. They are superimposed by the (more erratic) white bars, representing the observing hours. The graphic already starts with the first vertical sweep (46) on 18 December. Of course, Herschel avoided strong moonlight, which can be seen by the shorter turns around Full Moon. The longest observations, with even more than 12 hours, were made near New Moon. The hight density of the bars indicates that every possible moment was used for sweeping. The following day was the time for data evaluation, technical improvements and planning the next night. That meant enormous physical and psychological stress for the siblings. The graphic also shows the

relation between season and observation. The best month of 1784 was September. Graphics for later years show similar results, though the number of sweeps was decreasing, not caused by the observing conditions (Figure 5-22).

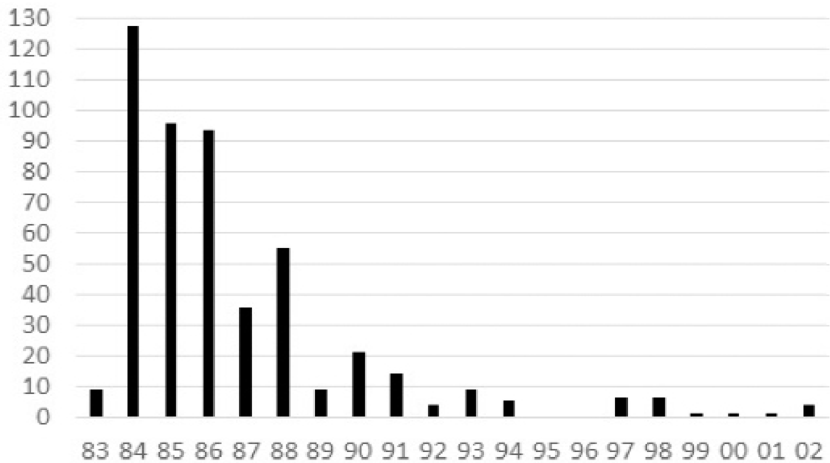


Figure 5-22: Annual number of sweeps between 1783 and 1802.

Figure 5-23 shows the relation between lunar phase and the number of observing nights in 1784. Though most nights were used about New Moon, there is still a significant number about 6 days after Full Moon towards the last quarter. Such observations started as early as possible.

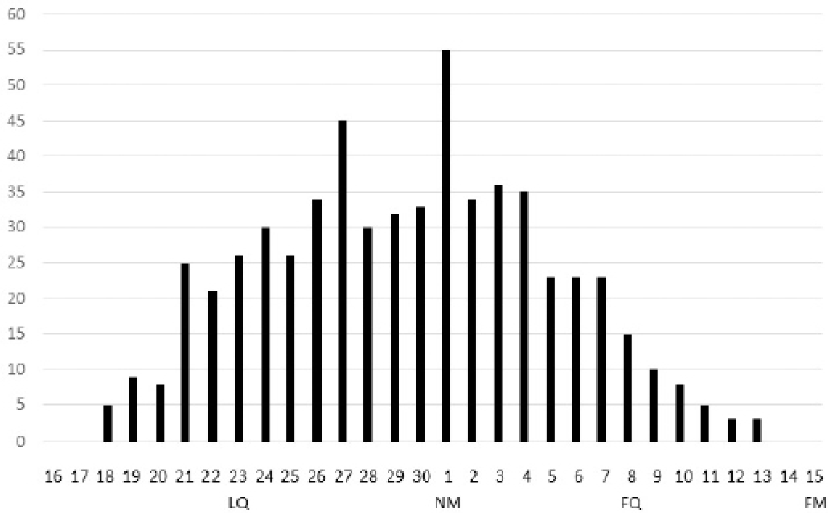


Figure 5-23: Relation between lunar phase (days after New Moon) and observing hours for the record year 1784 (see text); FQ/LQ = first/last quarter, FM/M = Full/New Moon.

Because every possible night was used in 1784, one can estimate the rate of bad weather. Assuming that about 10 days around Full Moon were omitted, this amounts to 120 nights for the year. Taking the 128 observing nights, there is a rest of 117 nights. Though not much influenced by moonlight, they remained unused. One can conclude that this was mainly due to bad weather. Applying a rate of about 50% for the full year, one gets a reasonable value for southern England. It is not astonishing that the Herschels achieved the maximum out of it!

Table 5-20 shows statistical data for the sweep period 1783–1802 (extreme values for various categories). Of course, the record year 1784 dominates. The first object discovered is the galaxy NGC 7184 in Aquarius (sweep 1, 28 October 1783), the last is the galaxy NGC 2650 in Ursa Minor (sweep 1112, 30 September 1802).

Category	Value	Year	Remarks
number of nights	128	1784	
longest period (days)	10	1784	4–13 September
longest break (days)	1131	1794–97	18 Oct. 1794 – 22 Nov. 1797
number of sweeps	275	1784	
longest night (hours)	12.8	1786	
lowest elevation (°)	6.3	1790	NGC 1366 (Gx, For); Figure 2-181
lowest PD (°)	7	1802	NGC 2495 (Gx, UMi)
observed objects	793	1784	
sweeps without objects	92	1784	
new objects	648	1784	
uncatalogued objects	13	1786	
re-observed objects	305	1786	
brightest object (mag)	4.6	1788	NGC 6633 (OC, Oph
faintest object (mag)	15.5	1784	NGC 2843 (Gx, Cnc)
smallest object (")	16	1784	NGC 6629 (PN, Sgr)
multiple systems	55	1784	46 pairs
closest double galaxy (")	30	1785	NGC 545/47 (Cet)
Messier objects	93	1784	
new double stars	22	1784	
new garnet stars	4	1784	
star gages	643	1784	
vacant places	78	1784	

Table 5-20: Extreme values for different categories in the sweep period 1783–1802.

Criterium	Variations	Sweeps
	Datchet	413
	Clay Hall	137
	Slough	562
sweep mode	east-west ('oscillation')	41
	up-down ('sweeping motion')	1071
sweep type	regular	991
	not registered (16 objects)	76
	half swept (132 objects)	45
sweep yield	no object	514
	only one object	215
	more than one object	383
time	Greenwich Mean Time	63

	(GMT)	
	sidereal (ST)	1049
tube direction	south meridian	975
	north meridian, above the pole	110
	north meridian, under the pole	22
	east	5
focus	Newtonian	601
	front-view	511
position determined by	sketch	61
	reference star	1051
PD zone (Flamsteed stars)	0° to 45°	643
	0° to 123°	469
reference star (source)	Flamsteed	925
	Wollaston	175
	Bode	12

Table 5-21: Number of sweeps related to interesting criteria and their variations.

Table 5-21 summarizes the main criteria to distinguish the sweeps. The number of sweeps sum up to 1112 for the individual variations. Concerning the sweep type, it should be noted that even in the 76 ‘not registered’ sweeps, 16 objects were observed. Sometimes the corner coordinates of the sweep area were not clearly defined. In the ‘half swept’ case, 132 objects were observed. Figure 5-24 shows these areas and the relevant objects.

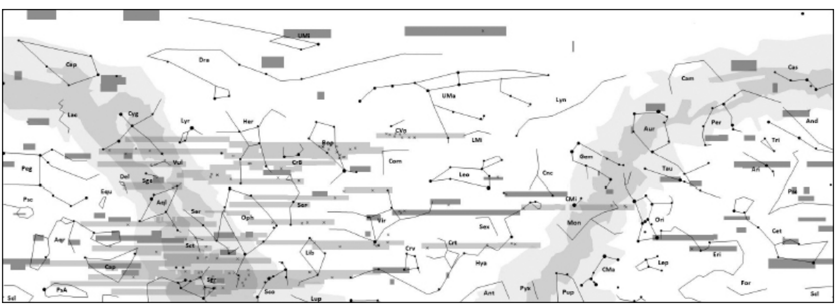


Figure 5-24: 'Not registered' sweeps (darker rectangle) and 'half swept' areas (lighter rectangle) and their objects (cross); only the brightest stars are shown.

Table 5-22 lists the nightly sessions lasting more than 10 hours. Due to occasional rest breaks (usually after 2 to 3 hours) after which new sweeps were started, the total observation time was shorter. Up to 14 sweeps were made in the listed nights.

Date	Time (h)	Obs (h)	AR range	Decl	N	Sweeps	Moon	Remarks
1 Jan. 1786	12.80	9.97	0h – 13h	+0	4	504–507	0.07	C
9 Dec. 1784	12.43	10.00	23h – 11h	-24	5	330–334	-0.20	D
28 Dec. 1785	12.28	7.38	1h – 11h	+9	4	495–498	-0.20	C
23 Jan. 1784	12.27	8.12	2h – 14h	+7	17	95–111	0.07	D
21 Dec. 1786	11.88	6.05	0h – 12h	-4	4	657–660	0.07	S, FV
19 Dec. 1783	11.75	6.63	0h – 11h	+4	8	52–59	-0.29	D
13 Dec. 1784	11.67	8.50	0h – 12h	+3	6	338–343	0.07	D
3 Feb. 1788	11.58	6.87	3h – 15h	+9	6	801–806	-0.27	S, FV
24 Jan. 1784	11.27	7.92	3h – 14h	+4	14	112–125	0.14	D
1 Nov. 1788	11.18	8.27	21h – 8h	+61	5	875–879	0.21	S, FV, above pole
17 Nov. 1784	11.03	7.33	22h – 9h	+6	5	319–323	0.33	D
30 Dec. 1785	10.98	9.08	0h – 11h	-24	4	499–502	-0.07	C
6 Jan. 1785	10.77	9.08	2h – 12h	-3	3	351–353	-0.33	D
18 Jan. 1784	10.57	7.30	3h – 13h	+11	9	80–88	-0.27	D
15 Oct. 1784	10.48	8.58	20h – 7h	+16	4	290–293	0.07	D
24 Oct. 1786	10.47	8.60	21h – 7h	+43	3	620–622	0.14	S, FV
16 Oct. 1784	10.45	8.03	20h – 7h	+9	3	294–296	0.14	D
24 Feb. 1786	10.35	7.78	5h – 16h	+4	4	529–532	-0.27	C
26 Oct. 1786	10.22	6.65	21h – 8h	+28	4	625–628	0.29	S, FV

Table 5-22: Longest observing sessions. 'Time' = total duration, 'Obs' = total observing time. The 'RA range' gives rough RA limits, 'Decl' the mean declination (of all sweeps in that night); N = number of sweeps performed in that night; 'Moon' = phase. Remarks: D = Datchet, C = Clay Hall, S = Slough, FV = front-view.

5.3. Messier objects, telescopes and the Solar System

M	Con	T	V	Remarks	R	S	W	C	J	M	Con	T	V	Remarks	R	S	W	C	J
1	Tau	EN	8.4	Crab Nebula	8	2	**10**	1	2	**56**	Lyr	GC	8.4		7		**7**	4	7
2	Aqr	GC	6.6		11	5	**16**	2	4	**57**	Lyr	PN	8.8	Ring Nebula	10	1	**11**		6
3	CVn	GC	6.3		5	3	**8**	4	6	**58**	Vir	Gx	9.7			3	**3**		4
4	Sco	GC	5.4		2	2	**4**	1		**59**	Vir	Gx	9.6			2	**2**		3
5	Ser	GC	5.7		10	4	**14**	3	2	**60**	Vir	Gx	8.8			2	**2**		6
6	Sco	OC	4.2	Butterfly Cluster	1	2	**3**		1	**61**	Vir	Gx	9.7	I 139		2	**2**		3
7	Sco	OC	3.3	Ptolemy's Cluster	1		**1**		2	**62**	Oph	GC	6.4		2	2	**4**		5
8	Sgr	EN	5.8	Lagoon Nebula (V 13)	3	2	**5**		3	**63**	CVn	Gx	8.6	Sunflower Galaxy		2	**2**		1
9	Oph	GC	7.8		1	3	**4**	1	2	**64**	Com	Gx	8.5	Black Eye Galaxy		6	**6**		4
10	Oph	GC	6.6		2	2	**4**	2	5	**65**	Leo	Gx	9.3		2	3	**5**		5
11	Sct	OC	5.8	Wild Duck Cluster	12		**12**	2	2	**66**	Leo	Gx	8.9		2	3	**5**		6
12	Oph	GC	6.1		2	2	**4**	4	3	**67**	CNC	OC	6.9		3	1	**4**	2	5
13	Her	GC	5.8		12	1	**13**	6	5	**68**	Hya	GC	7.3			3	**3**		1
14	Oph	GC	7.6		3	2	**5**	4	2	**69**	Sgr	GC	8.3			1	**1**		3
15	Peg	GC	6.3		13	2	**15**	5	6	**70**	Sgr	GC	7.8			1	**1**		3
16	Ser	OC	6.0		1	1	**2**	1	1	**71**	Sge	GC	8.4	not identified	8	2	**10**	2	4
17	Sgr	EN	6.0	Omega Nebula	2	2	**4**	1	5	**72**	Aqr	GC	9.2		7	2	**9**		3
18	Sgr	OC	6.9		1	2	**3**		1	**73**	Aqr	SG	8.9		3	1	**4**		
19	Oph	GC	6.8		1	2	**3**		5	**74**	Psc	Gx	9.4		7	1	**8**		2
20	Sgr	EN	8.5	Trifid Nebula (IV 41, V 10-12)	1	2	**3**	1	6	**75**	Sgr	GC	8.6		6	3	**9**		3
21	Sgr	OC	5.9		1	1	**2**	1	1	**76**	Per	PN	10.1	Little Dumbbell (I 193)	3	1	**4**		2
22	Sgr	GC	5.2		4	2	**6**	2	4	**77**	Cet	Gx	8.9		9	5	**14**		2
23	Sgr	OC	5.5		2	2	**4**	1	3	**78**	Ori	EN	8.0		2	3	**5**	1	2
24	Sgr	SC	4.6	Sagittarius Star Cloud	1		**1**		1	**79**	Lep	GC	7.7	not identified	4	1	**5**		
25	Sgr	OC	4.6		2	1	**3**	1		**80**	Sco	GC	7.3			3	**3**		2
26	Sct	OC	8.0		3	2	**5**	1	1	**81**	UMa	Gx	6.9	Bode's Nebulae	2	2	**4**	10	2
27	Vul	PN	7.4	Dumbbell Nebula	7	2	**9**	5	4	**82**	UMa	Gx	8.4	Bode's Nebulae (IV 79)	3	2	**5**	10	1
28	Sgr	GC	6.9		6	2	**8**		2	**83**	Hya	Gx	7.5			2	**2**		4
29	Cyg	OC	6.6		4	2	**6**	4	1	**84**	Vir	Gx	9.1			1	**1**		1
30	Cap	GC	6.9		8	3	**11**	3	2	**85**	Com	Gx	9.1			1	**1**		2
31	And	Gx	3.4	Andromeda Nebula	13	4	**17**	9	2	**86**	Vir	Gx	8.9			1	**1**		2
32	And	Gx	8.1		4	5	**9**	2	3	**87**	Vir	Gx	8.6			2	**2**		5
33	Tri	Gx	5.7	Triangulum Nebula (V 17)	6	3	**9**	3	1	**88**	Com	Gx	9.6			2	**2**		6
34	Per	OC	5.2		3	3	**6**		4	**89**	Vir	Gx	9.8			1	**1**		4
35	Gem	OC	5.1		8	1	**9**		2	**90**	Vir	Gx	9.5			2	**2**		
36	Aur	OC	6.0		4	2	**6**	3	4	**91**	Com	Gx	10.2	II 120		2	**2**		3
37	Aur	OC	5.6		8		**8**	3	4	**92**	Her	GC	6.5		7	1	**8**	4	2
38	Aur	OC	6.4		4	2	**6**	2	1	**93**	Pup	OC	6.2		4	1	**5**	1	1
39	Cyg	OC	4.6		1	1	**2**		1	**94**	CVn	Gx	8.2		1	2	**3**	2	6
40	UMa	SP	9.0	Winnecke 4				1		**95**	Leo	Gx	9.7	I 26	1	3	**4**		6
41	CMa	OC	4.5		1	2	**3**	1	1	**96**	Leo	Gx	9.3		1	3	**4**		5
42	Ori	EN	4.0	Orion Nebula	38	5	**43**	1	10	**97**	UMa	PN	9.9	Owl Nebula	3	2	**5**		2
43	Ori	EN	6.8		5	3	**8**		10	**98**	Com	Gx	10.1			3	**3**		4
44	CNC	OC	3.1	Praesepe	2	1	**3**	1	1	**99**	Com	Gx	9.9			2	**2**		4
45	Tau	OC	1.6	Pleiades	2	1	**3**	1	1	**100**	Com	Gx	9.4			1	**1**		4
46	Pup	OC	6.1		3	2	**5**	1	1	**101**	UMa	Gx	7.9	Pinwheel Galaxy	3	2	**5**	1	1
47	Pup	OC	4.4	VIII 38	2	2	**4**	1	2	**102**	Dra	Gx	9.9	I 215		1	**1**		1
48	Hya	OC	5.8	VI 22	1	3	**4**	1	3	**103**	Cas	OC	7.4		3	1	**4**	2	2
49	Vir	Gx	8.4	I 7		2	**2**		7	**104**	Vir	Gx	8.0	Sombrero Galaxy (I 43)		2	**2**		1
50	Mon	OC	5.9		1	3	**4**		4	**105**	Leo	Gx	9.3	I 17		5	**5**		4
51	CVn	Gx	8.4	Whirlpool Nebula	2	2	**4**	4	5	**106**	CVn	Gx	8.4	V 43		3	**3**		4
52	Cas	OC	6.9		4	2	**6**	2	1	**107**	Oph	GC	7.8	VI 40		1	**1**		
53	Com	GC	7.7		4	2	**6**		7	**108**	UMa	Gx	10.0	V 46		2	**2**		1
54	Sgr	GC	7.7		2	2	**4**		4	**109**	UMa	Gx	9.8	IV 61		2	**2**		2
55	Sgr	GC	6.3		1	3	**4**	1	2	**110**	And	Gx	8.1	V 18	1	4	**5**	4	1

Table 5-23: Messier objects, seen by William (W), Caroline (C) and John (J). William's observations are divided into review (R) and sweep (S). Some objects were not identified by him and thus catalogued (e.g. M 33 = V 17).

In the appendix of the *Scientific Papers*, Dreyer presents Herschel's 'Unpublished Observations of Messier's Nebulae and Clusters' (see section 6.4). The collection concerns only the 103 'original' Messier objects. Here we treat this topic from a modern perspective, including M 104–110.[1047] Dreyer missed some observations, hidden

in the documents. Table 5-23 gives all observations, made by the Herschel family. The data differ from Dreyer's collection. It should be noted that Caroline created a register sheet for each M-object (see Figure 5-25 for M 1).

William's observations were made in the reviews (R) and sweeps (S); column 'W' gives the sum. Of course, M 42 is the top-scorer with 43 observations (see Table 3-14). M 40 is the only object, never seen by William; Caroline helped out here. She missed 58 Messier objects (it was not her plan to view all). John missed only seven. It is interesting that he never observed the bright globular cluster M 107 (VI 40) in Ophiuchus, though it is listed in Caroline's *Zone Catalogue*. It is one of the 796 Herschel objects, not seen (or searched) by him.

Table 5-24 shows that Herschel independently discovered 20 Messier objects, among them are all seven additional ones. Column 'Id' gives his identification (as Messier object) or designation in the three catalogues ('C'). 'N' and 'NS' are the numbers of all observations and that in the sweeps ('Sw'). 'Tel' gives the telescope: 6.2 = 7-ft, 9.0 = 10-ft, 12.0 = small 20-ft, 18.7 = 20-ft, 24.0 = X-foot.

M	Id	C	N	NS	Sw	Date	Tel	NGC	Con	V	Type	Remarks
8	-		6	2		24 Aug. 1780	6.2	6533	Sgr	5.8	EN	Lagoon Nebula, Hodierna 1654
	-					3 May 1783	9.0					
	M 8					2 Aug. 1783	12.0					
	V 13	1			223	22 May 1784	18.7					not identified with M 8
	V 13				236	12 Jul. 1784	18.7					
20	-		3	2		2 Aug. 1783	6.2	6514	Sgr	8.5	EN+OC	Trifid Nebula, Messier 1763
	V 10	1			236	12 Jul. 1784	18.7					
	V 11	1			236	12 Jul. 1784	18.7					
	V 12	1			236	12 Jul. 1784	18.7					
	IV 41	2			566	26 May 1786	18.7					
33	M 33		10	3		2 Aug. 1783	6.2	598	Tri	5.7	Gx	Triangulum Nebula, Hodierna 1654
	M 33					24 Aug. 1783	6.2					
	V 17	1			266	11 Sep. 1784	18.7					not identified with M 33
	V 17				268	12 Sep. 1784	18.7					
	V 17				680	11 Jan. 1787	18.7					
	M 33					28 Oct. 1794	6.2					
	M 33					28 Dec. 1799	9.0					
	M 33					9 Dec. 1805	24.0					
	M 33					25 Sep. 1810	24.0					
	M 33					4 Oct. 1810	24.0					
47	-		4			15 Feb. 1781	6.2	2422	Pup	4.4	OC	Hodierna 1654
	-					12 Oct. 1782	6.2					
	VIII 38	1			366	4 Feb. 1785	18.7					
	VIII 38			2	540	19 Mar. 1786	18.7					
48	-		4	3		8 Mar. 1783	6.2	2548	Hya	5.8	OC	Bradley 1727
	VI 22	2			519	1 Feb. 1786	18.7					
	VI 22				641	28 Nov. 1786	18.7					
	M 48				935	5 Mar. 1790	4.2					
49	I 7	1	2	2	105	23 Jan. 1784	18.7	4472	Vir	8.4	Gx	Messier 1771
	I 7				498	28 Dec. 1785	18.7					
61	I 139	2	2	2	553	17 Apr. 1786	18.7	4303	Vir	9.7	Gx	Oriani 1779
	I 139				558	30 Apr. 1786	18.7					
71	-		1	1		4 Nov. 1782	6.2	6838	Sge	8.4	GC	de Chéseaux 1745
76	I 193	2	2	1	780	12 Nov. 1787	18.7	651	Per	10.1	PN	Little Dumbbell, Méchain 1780
	M 76					18 Oct. 1805	6.2					
79	-		1	1		4 Mar. 1783	6.2	1904	Lep	7.7	GC	Méchain 1780
82	M 82		5	2		6 Aug. 1783	12.0	3034	UMa	8.4	Gx	Koehler 1779
	M 82				1100	8 Nov. 1801	18.7					
	IV 79				1112	30 Sep. 1802	18.7					HON 4

M	Id	C	N	NS	Sw	Date	Tel	NGC	Con	V	Type	Remarks
	M 82					23 Dec. 1805	24.0					
	M 82					26 Nov. 1810	24.0					
91	II 120	1	2	2	187	8 Apr. 1784	18.7	4548	Com	10.2	Gx	Messier 1781
	II 120				691	14 Jan. 1787	18.7					
	M 95		4	3		18 Dec. 1783	18.7	3351	Leo	9.7	Gx	Méchain 1781
	M 95				164	11 Mar. 1784	18.7					
	I 26	1			177	19 Mar. 1784	18.7					
	M 95				188	12 Apr. 1784	18.7					
102	I 215	2	1	1	842	5 May 1788	18.7	5866	Dra	9.9	Gx	Méchain 1781
104	I 43	1	2	2	210	9 May 1784	18.7	4594	Vir	8.0	Gx	Sombrero Galaxy, Méchain 1781
	I 43				819	11 Mar. 1788	18.7					
105	I 17	1	5	5	164	11 Mar. 1784	18.7	3379	Leo	9.3	Gx	Méchain 1781
	I 17				177	19 Mar. 1784	18.7					
	I 17				188	12 Apr. 1784	18.7					
	I 17				531	24 Feb. 1786	18.7					
	I 17				555	22 Apr. 1786	18.7					
106	V 43	2	3	3	816	9 Mar. 1788	18.7	4258	CVn	8.4	Gx	Méchain 1781
	V 43				823	1 Apr. 1788	18.7					
	V 43				830	10 Apr. 1788	18.7					
107	VI 40	3	1	1	1043	12 May 1793	18.7	6171	Oph	7.8	GC	Méchain 1782
108	V 46	3	2	2	922	17 Apr. 1789	18.7	3556	UMa	10.0	Gx	Méchain 1781
	V 46				925	24 Apr. 1789	18.7					
109	IV 61	3	2	2	919	12 Apr. 1789	18.7	3992	UMa	9.8	Gx	Méchain 1781
	IV 61				920	14 Apr. 1789	18.7					
110	-		5	4		24 Oct. 1783	6.2	205	And	8.1	Gx	Messier 1773; CH: 27 Aug. 1783
	V 18	1			282	5 Oct. 1784	18.7					
	V 18				613	17 Oct. 1786	18.7					
	V 18				621	24 Oct. 1786	18.7					
	V 18				623	25 Oct. 1786	18.7					

Table 5-24: Messier objects, catalogued by Herschel (see text).

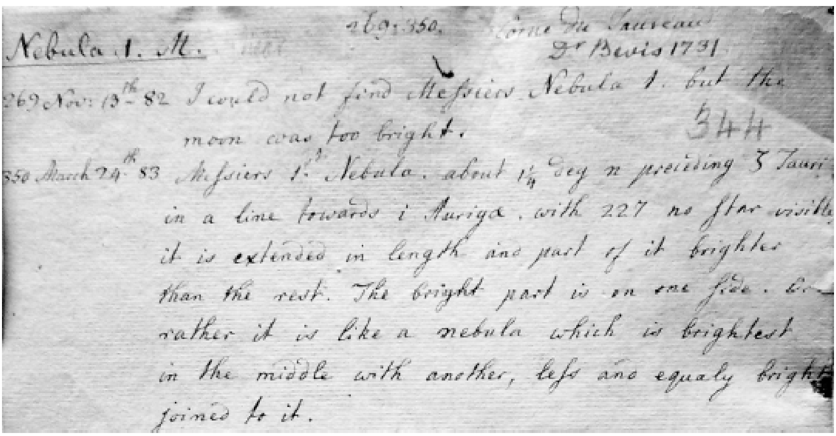

Nebula 1. M. 269. 350. Comet du Taureau Dr Bevis 1731
269 Nov: 13th 82 I could not find Messiers Nebula 1. but the moon was too bright. 344
350 March 24th 83 Messiers 1st Nebula. about 1¼ deg n preceding ζ Tauri in a line towards ι Aurigæ, with 227 no star visible it is extended in length and part of it brighter than the rest. The bright part is on one side. Or rather it is like a nebula which is brightest in the middle with another, less and equally bright joined to it.

Figure 5-25: Part of Caroline's register sheet for M 1; there is one for each of the 103 Messier objects. The document is archived at the *Royal Society* (RS MS/344).

Herschel's observations of non-stellar objects were made between 1 March 1774 and 16 April 1817. The first target, the Orion Nebula (M 42), was observed with a 5.5-ft reflector. The last was the

globular cluster M 15 in Pegasus; the 10-ft reflector was used. Table 5-25 shows the number of objects and observations.

Objects	Number	Observations	Remarks
catalogued	2426	3540	excluding M 1–103, including M 104–110
uncatalogued	71	75	excluding M 71, M 79 and M 82
Messier	103	557	original catalogue: M 1–103
Sum	**2600**	**4172**	

Table 5-25: Statistic of all observations.

Table 5-26 lists the telescopes and the number of observations of non-stellar objects, made with them. Table 5-27 shows the non-stellar objects, not seen in a sweep but otherwise, and Table 5-28 list the nine non-stellar objects, observed after the sweep campaign.

Aperture (in)	Focus (ft)	All	Messier	Remarks
naked eye	-	**9**	7	M 13, M 15, M 35, M 44, M 45, NGC 752, NGC 2244
2.0	3.5	**2**	1	Dolland refractor
4.0	7	**1**	1	Newtonian
4.2	2.25	**8**	7	small sweeper, Newtonian
4.5	5.5	**3**	3	Newtonian
6.2	7	**180**	136	Newtonian
9.0	10	**96**	87	Newtonian
12.0	20	**44**	43	small 20-foot, Newtonian
18.7	20	**3865**	248	large 20-foot, Newtonian/front-view
24.0	10	**63**	57	large 10-foot (X-foot), Newtonian
24.0	24	**2**	-	'Spanish telescope', front-view
48.0	40	**16**	7	front-view

Table 5-26: Instruments and the number of observations of non-stellar objects, made with them. Column 'All' refers to all objects; 'Messier' concerns the subset of Messier objects.

NGC	M	N	Period	Telescopes	V	Con	Type	Discoverer	Remarks
6705	11	12	12 Sep. 1779 – 3 Oct. 1810	7-ft, 10-ft, X-ft	5.8	Sct	OC	Kirch	Wild Duck Cluster
6530		1	24 Aug. 1780	7-ft	4.6	Sgr	OC	Hodierna	
6535		1	24 Aug. 1780	7-ft	9.3	Ser	GC	Herschel	
1981		1	23 Oct. 1780	7-ft	4.2	Ori	OC	Herschel	
IC 4665		2	15 Jul. 1781 – 31 Jul. 1783	7-ft	4.2	Oph	OC	de Chéseaux	
2099	37	8	29 Oct. 1782 – 23 Nov. 1805	7-ft, 10-ft, X-ft	5.6	Aur	OC	Hodierna	
6838	71	1	4 Nov. 1782	7-ft	8.4	Sge	GC	de Chéseaux	
1904	79	1	4 Mar. 1783	7-ft	7.7	Lep	GC	Méchain	
6779	56	7	6 May 1783 – 5 Jan. 1807	7-ft, 10-ft, X-ft	8.4	Lyr	GC	Messier	
6475	7	1	30 Jul. 1783	small sweeper	3.3	Sco	OC	Ptolemy	Ptolemy's Cluster
IC 4715	24	1	2 Aug. 1783	small 20-ft	4.6	Sgr	SC	Messier	Sagittarius Star Cloud
6871		1	23 Sep. 1783	7-ft	5.2	Cyg	OC	Herschel	
6819		3	14 May 1784 – 30 Dec. 1806	7-ft, 10-ft	7.3	Cyg	OC	Herschel	
7441		1	28 Aug. 1789	40-ft	13.8	Aqr	Gx	Herschel	Figure 2-174
IC 1339		1	29 Sep. 1791	40-ft	13.2	Cap	Gx	Herschel	Figure 2-174
4831		1	9 Apr. 1793	40-ft	12.5	Hya	Gx	Herschel	Figure 2-174

Table 5-27: Non-stellar objects not seen by Herschel in a sweep, but viewed with other telescopes. They are sorted by the date of the first observation. 'N' gives the number of observations.

NGC	H	Date	Tel	V	Con	Type	Remarks
6894	IV 13	18 Oct.	7-ft	12.3	Cyg	PN	3 Jan. 1807 (20-ft)
7009	IV 1	18 Oct.	7-ft	8.0	Aqr	PN	Saturn Nebula, 25 Sep. 1810 (X-ft)
7662	IV 18	18 Oct.	7-ft	8.3	And	PN	Blue Snowball, 1 & 3 Jan. 1807 (X-ft, 20-ft)
1003	II 238	23 Nov.	X-ft	11.5	Per	Gx	
1535	IV 26	30 Dec.	10-ft	9.6	Eri	PN	
6819	-	30 Dec.	10-ft	7.3	Cyg	OC	
1980	V 31	31 Dec.	10-ft		Ori	EN	ι Orionis Nebula (part of M 42), 9 Jan. 1811
869	VI 33	16 Apr.	10-ft	5.3	Per	OC	Double Cluster
884	VI 34	16 Apr.	10-ft	6.1	Per	OC	Double Cluster

Table 5-28: The nine non-stellar objects, observed by Herschel after the sweep campaign, which are not in the (extended) *Messier Catalogue*. They are sorted by the observation date; four were viewed more than once.

It is also interesting to analyse the annual observations of non-stellar objects from 1774 to 1817, divided into new, re-observed and Messier objects (Figure 5-26). The record year 1784 clearly dominates. In the sweeping period, the number of re-observations was, naturally, pretty high. Messier objects were always popular targets.

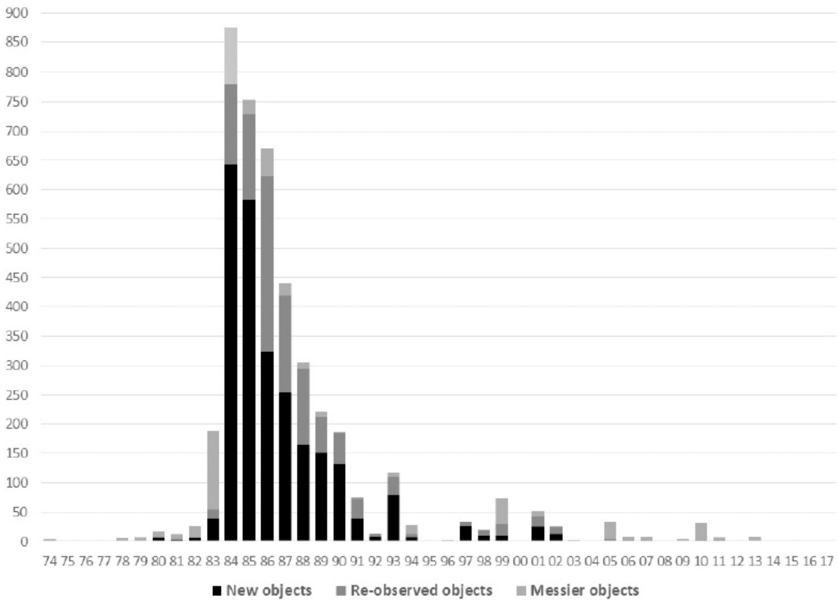


Figure 5-26: Herschel's annual observations of non-stellar objects (1774–1817).

There are only five cases, in which a planet was in the sweep area (in four it was on the path); they are listed in Table 5-29. The observations of Solar System objects and stars (single/double/multiple, red, variable), made beside the sweeps are shown in Table 5-30. The numbers refer to observations (not to a date). In most cases, several objects were observed, some in the daytime (Sun).

Planet	Date	Sw	Con	Description	Remarks
Jupiter	25 Oct. 1786	623	Ari	"Began again after an interruption by Jupiter."	
Uranus	14 Jan. 1787	688	Gem	"The Georgian Planet."	
Uranus	10 Feb. 1787	697	Gem	"The Georgian Planet. The 2 satellites pursue their course."	
Saturn	12 Aug. 1787	750	Aqr		not seen
Uranus	22 Feb. 1789	907	Cnc	"The Georgian Planet and its 2 satellites, both nearly south." (sketch)	3° W of M 44

Table 5-29: Planets in the sweep area. Saturn was missed, though only 33' north of the observed star ι Aqr. All observations were made with the front-view.

Year	Sun	Moon	Mercury	Venus	Mars	Jupiter	Saturn	Uranus	Ceres	Pallas	Juno	Vesta	Comets	Stars
1774		2				1	13							3
1775							4							1
1776		7					4							1
1777				2	4	1	5							2
1778						**15**	6							6
1779	2				10	12	5							52
1780		**20**		7	2	1	4							74
1781		9			21	5	11	17					3	102
1782				1									2	**116**
1783	1		1	8	**31**	3	11	8					4	6
1787		5			1	1	15	**31**					1	4
1788		5		1	2		6	2					3	
1789				2			53	8					1	
1790		2			1	2	12	14					6	4
1791		3		1			39	15					1	5
1792	5						15	9						18
1793	1	3		**20**			23	7					3	10
1794	5	2		4		8	13	16						3
1795	1					2	1	1					7	86
1796	1			19	3	9	5	8						91
1797			1				3	8					1	34
1798	1			2	1		**25**	4						15
1799	7			1				2					2	17
1800	38	1			1	1	1	3						10
1801	**164**	1		4	1		2	4	4					19
1802	62					2		2	**30**	**8**				51
1803	28	1				1	2			1				26
1804	21	1		2							**19**			24
1805	14				2	5	11						2	4
1806	11			1		1	15	1						2
1807	1	2				3	4	1				**12**	29	3
1808	11			1			4	2	3			7	19	1
1809	18			4	1	1	1	2						5
1810	4						2	2						2
1811													**30**	1
1812				3								3	7	
1813				1	1		1							22
1814							1					3		2
1815	1												2	
1816	5													
1817														5
1818	1													
1819	1												5	
Sum	404	64	2	84	82	74	317	167	37	9	19	25	128	827

Table 5-30: Observations of Solar System objects and stars beside the sweeps made from 1774 to 1819 (the years 1784–86 are missing due to sweeping). Bold number indicate the maximum number (best year); the high values for stars in 1779–82 are due to the second and third star review.

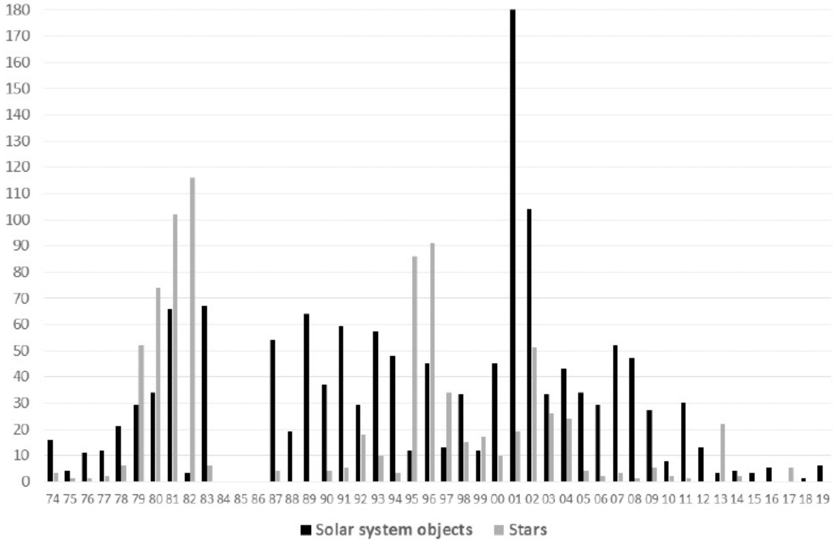


Figure 5-27: Herschel's annual observations (1774–1802) of Solar System objects and stars. Due to sweeping, there were no observations in 1784–86. The 1801 maximum is due to the Sun.

Herschel saw the four asteroids of his time: Ceres, Pallas, Juno and Vesta. But it is interesting to ask: Was there a chance to discover a minor planet during the sweep campaign? Being a keen observer, he would immediately notice the tiny, bright disk in the 20-ft. To tackle this issue, the author has developed a software tool to determine all sweeps containing a certain position. Feeding it with the coordinates of the four asteroids between autumn 1783 (start of sweeping) and autumn 1802 (end of sweeping, Juno still not found), one gets nine matches (Table 5-31). In four, an observed star was near; in two the asteroid was near to a star gage (otherwise it would have at least been counted). A galaxy was near twice; NGC 5331 (III 929) was discovered in the sweep; NGC 7184 (II 1) was Herschel's first discovery, right before sweeping started. Except for one case (the 'not registered' sweep 578) there was a realistic chance for Herschel to discover an asteroid. Of course, a similar search was made for Neptune. It brought no matches (see section 1.3.2).

Sw	Date	Asteroid	AR	PD	Con	V	Remarks
80	18 Jan. 1784	**Vesta**	02 47 32	79 14	Ari	7.7	3° W of star
185	27 Mar. 1784	**Pallas**	16 38 41	73 36	Her	9.2	46' NE of star
210	9 May 1784	**Ceres**	15 22 10	100 26	Lib	9.0	1.1° SW of star
220	19 May 1784	**Pallas**	16 14 23	63 24	Her	10.3	between two gages (1°)
430	1 Sep. 1785	**Ceres**	21 37 57	119 18	PsA	7.9	near gage (1.6°)
467	27 Oct. 1785	**Ceres**	21 27 36	117 23	PsA	8.8	48' SE of star
578	23 Aug. 1786	**Juno**	19 55 37	98 41	Aql	9.3	sweep not registered
609	13 Oct. 1786	**Vesta**	21 54 16	112 21	Aqr	7.0	52' SE of II 1 (NGC 7184)
1044	13 May 1793	**Ceres**	13 40 50	88 21	Vir	7.4	1.6° S of III 929 (NGC 5331)

Table 5-31: Asteroids, located in a sweep area, but not seen (see text); the positions are for 1800.

The situation in sweep 609 on 13 October 1786 is remarkable. Herschel only missed Vesta by a few arcminutes (Figure 5-28). Being at the top of the sweep, he saw NGC 7184 (II 1) in Aquarius, known from its discovery in sweep 1 on 28 October 1783. The 10.9 mag edge-on galaxy now appeared in the front-view (a sketch was made). Due to the sweep record, the object was seen with an AR offset of $+35^s$ (western edge of the field of view) Herschel followed it by about 1½ fields for a detailed description. Then the tube was moved to the south towards the bottom of the sweep (breadth 2.2°). The field now almost touched Vesta's position. With a brightness of 7.0 mag, it would certainly have been recorded as an 'unknown star'. With a higher magnification it would surely have been identified as a new 'planet'. Alas, things went different.

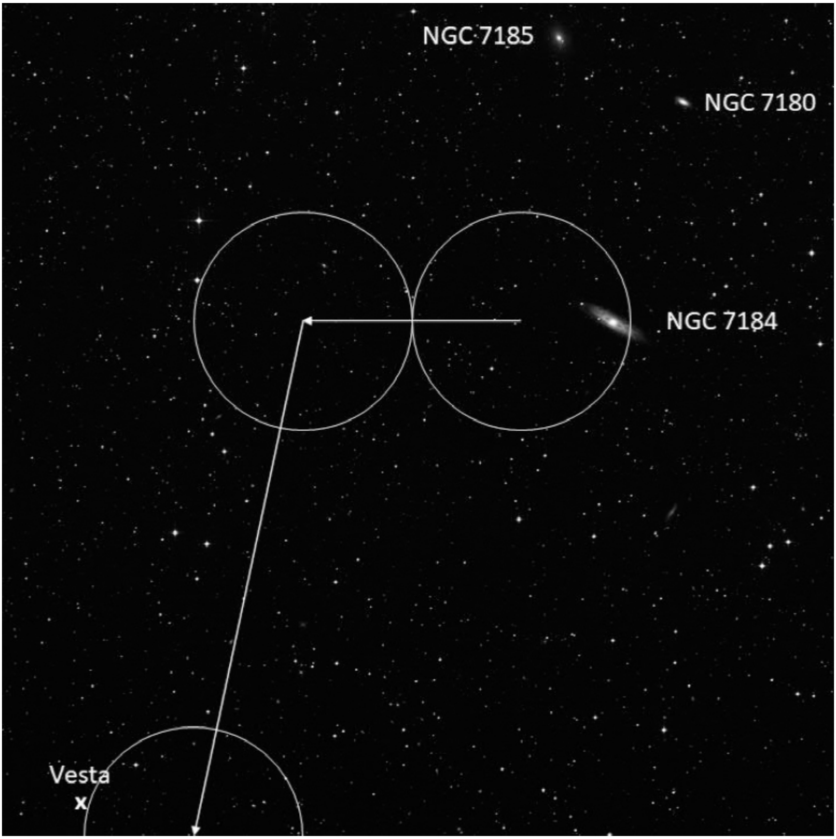


Figure 5-28: On 13 October 1786, Herschel's field of view almost touched the Vesta position (see text). 1048

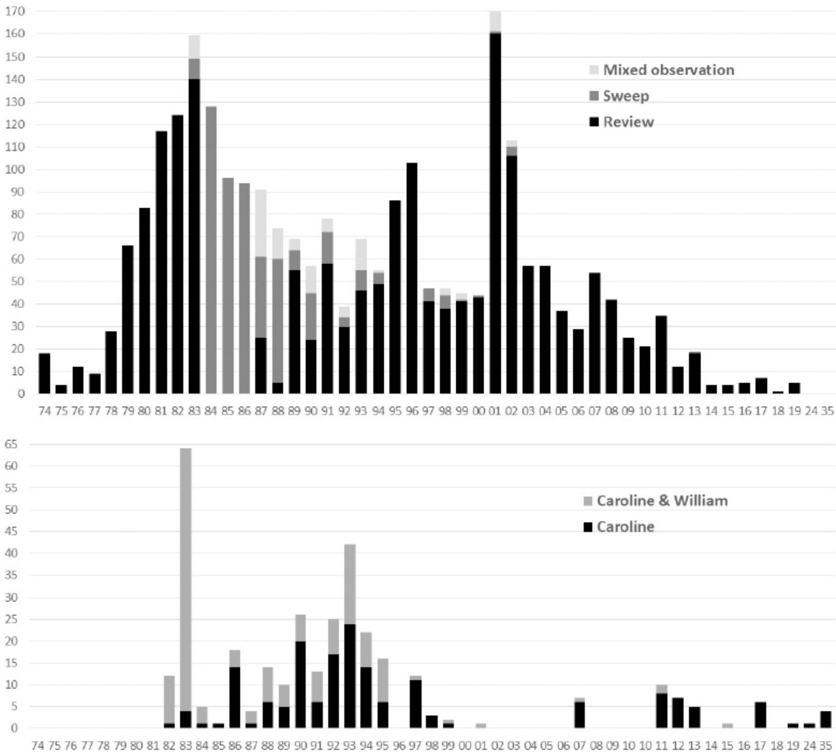


Figure 5-29: Annual observations of William (above) and Caroline (below); note the identical time scale (1774–1835).

Not only William was a diligent observer, but also Caroline, when they had time (Figure 5-29). William started on 1 March 1774; the first target was Saturn. The last was Comet Tralles on 7 June 1819. His annual observations are primarily separated into those, made in the reviews and sweeps. The sweep period, using the 20-ft, concerns the time between October 1783 and September 1802. The reviews dominate the time before and after this period. In the years 1774–82 the 'star reviews' were made, searching for double stars with the 7-ft. In 1795 and 1796, there were no sweeps; the period was dedicated to planets. After 1802, the Sun, planets, asteroids and Messier objects were viewed with various telescopes. There are 14 years with both reviews and sweeps, made on different nights; note the single night in 1813, when the very last sweep (1113) was made. The 'mixed observation' bar indicates that both a review and sweep were made in the same night. Such a session started, for

instance, with observing a planet (10-ft), then a sweep was made with the 20-ft (or vice versa). Caroline started on 28 August 1782 with a small refractor. Many observations were made together with William, both using their own instrument. A large gap appeared between 1800 and 1811. Later she was again active (mainly alone) with the large sweeper.

1024 The formula also gives the time for an object to cross the field of view, depending on declination (see Figure 2-167).

1025 On 19 May 1784 (sweep 210), the asteroid Pallas was right between two such gages, thus Herschel missed its discovery!

1026 In the third of these gages, made on 21 May 1784, the 'hole in Scorpius' was found.

1027 15 minutes later 'left off' is noted; after a one-hour break, sweep 397 began.

1028 RAS W.2/8.3.

1029 'Sweeps calculated for 1800'; RAS C.3/2.1. For the sweeps 1–45 the information must be taken from the early records. Table 5-21 shows statistical features of all sweeps.

1030 Caroline compiled a list of 25 cases, RAS W.2/7. The same document contains a list of 'Places in the heavens which have not been swept, or have only been examined by Moonlight or twilight. No allowance is made here for lapping over in sweeping.' Half swept regions are marked. There is a separate list for polar regions.

1031 The German writer is unknown, but there is a great similarity to Dietrich's hand (Figure 3-32).

1032 See the revised version: Baily (1831).

1033 RAS C.3/2.3.

1034 HD refers to the *Henry Draper Catalogue*.

1035 King, Tr (Trumpler) and Cr (Collinder) refer to lists of open clusters.

1036 We have seven cases in the *Slough Catalogue*, 14 in the *General Catalogue*, seven in the *New General Catalogue* and 10 in the *Scientific Papers*.

1037 The other cases were already treated in former sections: III 5 in 3.1, III 6 in 2.2.1, IV 6 in 2.2.2, VI 8 in 2.2.4.

1038 For modern observations of non-stellar objects, see Steinicke (2019c).

1039 Herschel often called noticeable ensembles of stars 'patches'; a modern term is 'asterism'.

1040 This respects the possibility that, due to a position error or misfortune, the object exits at another (unknown) place.

1041 Steinicke (2021b).

1042 For instance, the brighter galaxies, like M 33, NGC 253 or M 104, are excluded.

1043 There is also the case of M 98: Herschel estimated an extent of 25', though it is no larger than 10' (see Figure 2-23).

1044 'Abell' refers to George Abell's *Catalogue of rich Clusters of galaxies*, 'Arp' to the *Atlas of Peculiar Galaxies* by Halton Arp and 'HCG' to Peter Hickson's catalogue of *Compact Groups of Galaxies*.

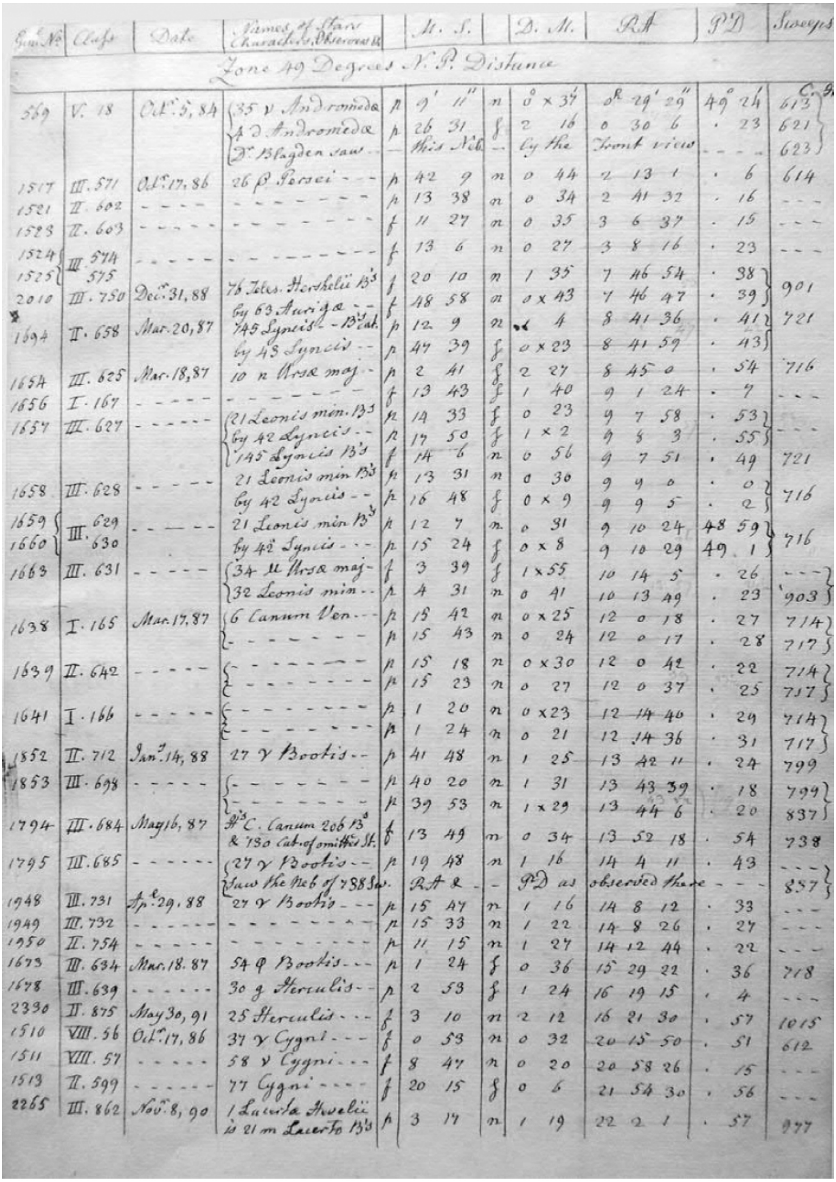
1045 This constellation offers 11 more non-stellar objects, within the reach of the 20-ft: nine galaxies, one open cluster and another planetary nebula (NGC 6765). The latter was found in 1864 by the German-born astronomer Albert Marth (1828–1897), using Lassell's 48-inch reflector on Malta; see Steinicke (2012c).

1046 Sweep 418 (1 August 1785), 430 (1 September 1785), 467 (27 October 1785) and 1053 (27 September 1785).

1047 For a modern presentation see the *Atlas of Messier Objects*; Stoyan, Binnewies, Friedrich (2015).

1048 The 12.0 mag galaxy NGC 7185 (II 603) was found on 11 September 1787 in sweep 754. The 12.2 mag galaxy NGC 7180, was not on William's sweep path and had to wait until John saw it on 23 September 1830 (h 2140).

6. Revisions of Herschel's catalogues



Gen. No	Class	Date	Names of Stars, Characters, Observations &c		M. S.		D. M.	RA	PD	Sweeps
			Zone 49 Degrees N. P. Distance							
569	V. 18	Oct. 5, 84	35 ν Andromedae	p	9′ 11″	n	0° × 37′	0h 29′ 29″	49° 24	613
			p δ Andromedae	p	26 31	f	2 16	0 30 6	. 23	621
			Dr. Blagden saw	—	this Neb	—	by the	front view	- - -	623
1517	III. 571	Oct. 17, 86	26 β Persei - - -	p	42 9	n	0 44	2 13 1	. 6	614
1521	II. 602	- - - -	- - - - - - - -	p	13 38	n	0 34	2 41 32	. 16	- - -
1523	II. 603	- - - - -	- - - - - - - - -	f	11 27	n	0 35	3 6 37	. 15	- - -
1524	III. 574	- - - - -	- - - - - - - - -	f	13 6	n	0 27	3 8 16	. 23	- - -
1525	575			f	20 10	n	1 35	7 46 54	. 38	901
2010	III. 750	Dec. 31, 88	76 Teles. Herschelii B's	f	48 58	n	0 × 43	7 46 47	. 39	
			by 63 Aurigae - -							
1694	II. 658	Mar. 20, 87	745 Lyncis - - B's Cat.	p	12 9	n	4	8 41 36	. 41	721
			by 43 Lyncis - -	p	47 39	f	0 × 23	8 41 59	. 43	
1654	III. 625	Mar. 18, 87	10 n Ursae maj -	p	2 41	f	2 27	8 45 0	. 54	716
1656	I. 167	- - - - -	- - - - - - - -	f	13 43	f	1 40	9 1 24	. 7	- - -
1657	III. 627	- - - - - -	21 Leonis min. B's	p	14 33	f	0 23	9 7 58	. 53	- - -
			by 42 Lyncis - -	p	17 50	f	1 × 2	9 8 3	. 55	
			145 Lyncis B's	f	14 6	n	0 56	9 7 51	. 49	721
			21 Leonis min B's	p	13 31	n	0 30	9 9 0	. 0	716
1658	III. 628	- - - - -	by 42 Lyncis - -	p	16 48	f	0 × 9	9 9 5	. 2	
1659	III. 629	- - — - -	21 Leonis min B's	p	12 7	n	0 31	9 10 24	48 59	716
1660	630		by 42 Lyncis - - -	p	15 24	f	0 × 8	9 10 29	49 . 1	
1663	III. 631	- - - - -	34 μ Ursae maj -	f	3 39	f	1 × 55	10 14 5	. 26	- - -
			32 Leonis min - -	p	4 31	n	0 41	10 13 49	. 23	903
1638	I. 165	Mar. 17, 87	6 Canum Ven - - -	p	15 42	n	0 × 25	12 0 18	. 27	714
			- - - - - - - -	p	15 43	n	0 24	12 0 17	. 28	717
1639	II. 642	- - - - -	- - - - - - - -	p	15 18	n	0 × 30	12 0 42	. 22	714
			- - - - - - - - -	p	15 23	n	0 27	12 0 37	. 25	717
1641	I. 166	- - - - - -	- - - - - - - - -	p	1 20	n	0 × 23	12 14 40	. 29	714
			- - - - - - - - -	p	1 24	n	0 21	12 14 36	. 31	717
1852	II. 712	Jan. 14, 88	27 γ Bootis - -	p	41 48	n	1 25	13 42 11	. 24	799
1853	III. 698	- - - - -	- - - - - - - -	p	40 20	n	1 31	13 43 39	. 18	799
			- - - - - - - - -	p	39 53	n	1 × 29	13 44 6	. 20	837
1794	III. 684	May 16, 87	B's C. Canum 206 B's & 730 Cat. of omitted St.	f	13 49	n	0 34	13 52 18	. 54	738
1795	III. 685	- - - - - -	27 γ Bootis - -	p	19 48	n	1 16	14 4 11	. 43	- - -
			Saw the Neb of 788 Sw.		RA & -	-	PD as	observed there	- - -	837
1948	III. 731	Apl. 29, 88	27 γ Bootis - - -	p	15 47	n	1 16	14 8 12	. 33	- - -
1949	III. 732	- - - - - -	- - - - - - - - -	p	15 33	n	1 22	14 8 26	. 27	- - -
1950	II. 754	- - - - - -	- - - - - - - - -	p	11 15	n	1 27	14 12 44	. 22	- - -
1673	III. 634	Mar. 18. 87	54 φ Bootis - - -	p	1 24	f	0 36	15 29 22	. 36	718
1678	III. 639	- - - - - -	30 g Herculis - -	p	2 53	f	1 24	16 19 15	. 4	- - -
2330	II. 875	May 30, 91	25 Herculis - - -	f	3 10	n	2 12	16 21 30	. 57	1015
1510	VIII. 56	Oct. 17, 86	37 γ Cygni - - -	f	0 53	n	0 32	20 15 50	. 51	612
1511	VIII. 57	- - - - -	58 ν Cygni - - -	f	8 47	n	0 20	20 58 26	. 15	- - -
1513	II. 599	- - - - - -	77 Cygni - - - -	f	20 15	f	0 6	21 54 30	. 56	- - -
2265	III. 862	Nov. 8, 90	1 Lacerta Hevelii is 21 m Lacertae B's	p	3 14	n	1 19	22 2 1	. 57	977

Already in the time of William Herschel, his three catalogues of non-stellar objects had inspired other authors. Francis Wollaston used parts of the data for his zonal star catalogue and the Berlin astronomer Johann Elert Bode made the results available for the German speaking audience. However, reliable revised versions appeared not until Herschel's death in 1822.

Caroline made the start with the legendary *Zone Catalogue*, prepared for her nephew. John, glad about this support, used the data treasure for his observations at Slough. The mission had the goal to confirm his father's objects and to determine better coordinates. Later the German astronomer Arthur Auwers and his Danish colleague Heinrich d'Arrest published major revisions. Next, the important work of John Louis Emil Dreyer pushed things to the limit, in the form of the *New General Catalogue* (1888) and the revision of the Herschel catalogues for the monumental *Scientific Papers* (1912). In 2008 the author published a modern version of the original catalogues, which has been continuously updated on the Internet since then.

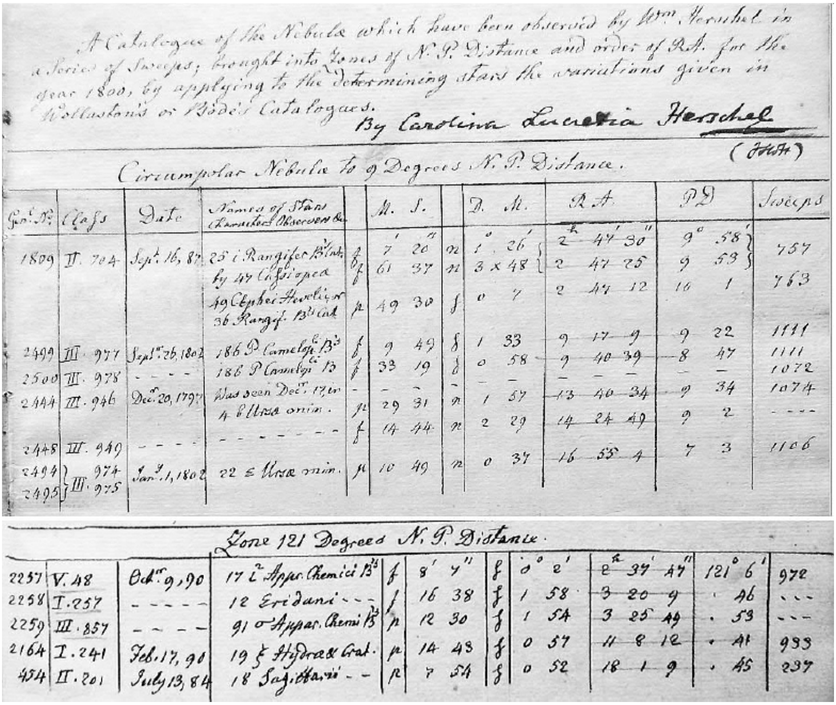
6.1. Caroline's *Zone Catalogue* – most famous but widely unknown

It is not surprising that the first reliable treatment of the original data is due to Caroline. After returning to Hanover on 28 October 1822, she found time for the revision of Herschel's catalogues of nebulae and star clusters. The result is known as the *Zone Catalogue*. The compilation was mainly made for John, who was planning to observe all Herschel objects at Slough with a new 20-ft reflector.

From England, Caroline had brought two important documents, the *Sweep Records No. 1–8* and the 'Catalogue of 2500 Nebulae and Star Clusters' with positions for 1800. She started the work in early 1824 and in September, when John visited her in Hanover, she could show him some progress. On 14 January 1825, she wrote to him, now settled in London:[1049] "I am now writing out the Catalogue of nebulae, and am at zone 30°, and hope to finish it for the Easter messenger". On 7 March, she informed John: "I am ready with the Catalogue of Nebulae, and have only to write, not a Preface, for I

shall write what I have to say at the end”.[1050] The *Zone Catalogue* was finished soon after and sent to London, together with the eight sweep books and a catalogue of the stars, seen in the sweeps.[1051] On 18 April 1825, her nephew happily replied: “I received this afternoon your most valuable packet containing your labours of the last year which I shall prize, and more than prize – shall use myself and make useful to others.”[1052]

The *Zone Catalogue* is a folio-volume of 104 handwritten pages (Figure 6-1).[1053] The non-stellar objects are arranged in declination zones, thus the name. The catalogue starts with the table ‘Circumpolar Nebulae to 9° N.P. Distance’, followed by PD zones 10° to 14° and 15° to 16°. All further zones up to the final one (PD 121°) show a constant breadth of 1°. Note that the zones for PD 31° and 32° are swapped. Inside a zone, the objects are ordered by AR. Many objects show more than one observation (only the date of the first is given). They are ordered by sweep number (date), though not always consistently. The last two pages contain, among other things, errata to the data of William’s catalogues. The title page of this chapter shows the entries for the PD zone 49°. As usual, all is accurately written.



A Catalogue of the Nebulæ which have been observed by Wm. Herschel in a Series of Sweeps; brought into Zones of N. P. Distance and order of R.A. for the year 1800, by applying to the determining stars the variations given in Wollaston's or Bode's Catalogues.

By Carolina Lucretia Herschel

(JHsch)

Circumpolar Nebulæ to 9 Degrees N. P. Distance.

Genl. No.	Class	Date	Names of Stars Characters Observers &c		M. S.		D. M.	R.A.	PD	Sweeps
1809	II. 704	Sept. 16, 87	25 i Rangifer Bode Cat.	f	7′ 20″	n	1° 26′	2h 47′ 30″	9° 58′	757
			by 47 Cassiopea	f	61 37	n	3 × 48	2 47 25	9 53	
			49 Cephei Hevelius	p	49 30	s	0 7	2 47 12	10 1	763
			36 Rangif. Bode Cat							
2499	III. 977	Septr. 26, 1802	186 P. Camelop. B	f	9 49	s	1 33	9 17 9	9 22	1111
2500	III. 978	- - - -	186 P. Camelop. B	f	33 19	s	0 58	9 40 39	8 47	1111
					— —		— —	— — —	— —	1072
2444	III. 946	Decr. 20, 1797	Was seen Decr. 17 in	-		-	1 57	13 40 34	9 34	1074
			4 δ Ursa min.	p	29 31	n	2 29	14 24 49	9 2	- - -
			- - - - - - - -	f	14 44	n				
2448	III. 949	- - - -						16 55 4	7 3	1106
2494 / 2495	III. 974 / 975	Jany. 1, 1802	22 ε Ursa min.	p	10 49	n	0 37			

Zone 121 Degrees N. P. Distance.

2257	V. 48	Octr. 9, 90	17 i² Appar. Chemici B	f	8′ 4″	s	0° 2′	2h 37′ 47″	121° 6′	972
2258	I. 257	- - - - -	12 Eridani - - -	f	16 38	s	1 58	3 20 9	. 46	. . .
2259	III. 857	- - - -	91 σ Appar. Chemi B	p	12 30	s	1 54	3 25 49	. 53	- - -
2164	I. 241	Feb. 17, 90	19 ξ Hydræ & Crat.	p	14 43	s	0 57	11 8 12	. 41	933
454	II. 201	July 13, 84	18 Sagittarii - -	p	7 54	s	0 52	18 1 9	. 45	237

Figure 6-1: The unpublished *Zone Catalogue*, finished in March 1825. 'Carolina Lucretia Herschel' was later added by John; it is her original German name.1054 Shown are the first and last PD zones: 0° to 9° and 121°, respectively.

Caroline took the data (Table 6-1) from the revised sweep records, ignoring the 'original' records. The data from the latter series were used for the printed Herschel catalogues. This led to some differences between the *Zone Catalogue* and the publications. There are early reference stars that do not appear in Caroline's final work.

Column	Meaning
Gen. No.	General number (GN) = object number (1–2500)
Class	H, class designation (I–VIII)
Date	discovery date
Names of Stars, Characters, Observers etc.	reference star/object
M.S. / D.M.	relative position (n = north, s = south)

R.A. / P.D.	absolute position (1800)
Sweeps	sweep number(s); 42–1112

Table 6-1: Columns of Caroline’s *Zone Catalogue*.

Caroline’s intention for the *Zone Catalogue* is expressed in a letter to John, dated 1 February 1826:[1055]

[…] for nothing else is wanting (and that is all) for my coming by the first steamboat to offer you the same assistance (when sweeping) as, by your father's instructions, I had been enabled to afford him. For an observer at your twenty-foot when sweeping wants nothing but a being that can and will execute his commands with the quickness of lightning (!), for you will have seen that in many sweeps six or twice six, &c., objects have been secured and described within the space of one minute of time.

I cannot think that any catalogue but the MS. one in zones (which was only intended for your own use) would facilitate the reviewing of the Nebulae, and you are the only one to whom 1885, viz., 2nd and 3rd class, out of the 2500, can be visible in your twenty-foot. Wollaston, who knew this, has given in his Catalogue only 1st and 4th, &c. classes of the first 1000, the second not having been published at that time, and they are without the yearly variation.

Bode has given the first and second Catalogues complete, and calculated the yearly variation to each by de Lambre's Tables. (See Bode’s preface, p. iv., line 18.) The last 500 were not published yet in 1800, or rather 1801. I only mention this that if you wanted the variations, and had a mind to trust to that catalogue of errors, it would save an immense trouble by copying them. But the more I think of these, the more I doubt if it would not be injuring the places of objects merely (though accurately) pointed out, to calculate them in the same manner as stars repeatedly observed in fixed instruments; and I doubt if your father noticed Bode's having done so.[1056]

Because of its intention, Caroline’s *Zone Catalogue* should have contained all objects observed in the sweeps (and listed in the records with all their observations). Unfortunately, this goal was not achieved. Only the vertical sweeps ($\geq$ 42) are included; also,

the eight additional objects (GC 2501–08) do not appear. 13 objects from the Herschel catalogues are missing. Moreover, 50 observations from 48 already listed objects, are not included. Some notes are given. A few typos do not matter.

Table 6-2 shows the statistics of the *Zone Catalogue* in comparison with the printed Herschel catalogues (plus the uncatalogued objects). Table 6-3 lists the reference objects; most of them are Flamsteed stars. 13 CVn and 37 Com were used 49 times, 34 Vir 48 times; 480 reference objects are used only once. The brightest reference stars are Sirius, Capella, Betelgeuse, Rigel, Spica, Fomalhaut, Deneb and Regulus. The faintest is the 7.8 mag star 653 Vir of Bode's catalogue. However, there are fainter reference objects, like the galaxy NGC 430 (II 447) in Cetus. Further 2650 stars were measured in the sweeps but not used to reference non-stellar objects. Table 6-4 lists the nine missing objects in the *Zone Catalogue*.

Catalogue	Column	Number	Remarks
HC + addition	observations	3779	sweeps and other observations
	different objects	2549	sweeps and other observations
ZC	entries	4025	sweeps 42–1112
	observations	3546	sweeps 42–1112
	different objects	2491	sweeps; one has no GN: III 984 (NGC 7810), H.MS.
	reference objects	1133	different sources (see following table)
	omitted objects	8	GN 2501–08 (not in HC)
	missing objects	13	in HC
	missing observation	34	in sweep records

Table 6-2: Statistics of the *Zone Catalogue* (ZC) in relation to the printed Herschel catalogues (HC) and its addition.

Reference object	Source	Number	Individual	Remarks
star	Flamsteed	3377	954	*British Catalogue*
star	Bode	397	130	*Uranographia*
star	Hevelius	73	16	mainly northern stars
star	T. Mayer	46	15	*Zodiacal Catalogue*
star	Lacaille	13	6	southern stars
star	Wollaston	6	2	
omitted star (O)	Caroline	25	7	
unknown star	Caroline	6	5	
double star	Caroline	7	1	N118 (sw 1066, Dra)
non-stellar object	Caroline	35	14	M 38, M 50, M 92, M 97, M 98, M 101, I 274, II 210, II 447, II 728, II 756, II 757, VI 1, VI 36
Georgium Sidus	Caroline	3	1	Uranus
no object	-	37	-	

Table 6-3: Reference objects in the *Zone Catalogue*. Number = multiple occurrence; individual = single objects.

Zone	GN	H	NGC	Sw	Date	Con	V	Remarks
22°	267	II 119	4540	187	4 Aug. 1784	Com	11.7	II 94
31°	2191	III 835	5526	948	17 Mar.1790	UMa	13.4	II 804
50°	574	III 198	946	283	6 Oct. 1784	And	13.2	eastern sweep
73°	580	II 243	57	288	11 Oct. 1784	Psc	11.6	II 241
80°	48	I 8	4698	106	23 Jan. 1784	Vir	10.6	III 6, near M 49
81°	46	II 19	4470	105	23 Jan. 1784	Vir	12.1	II 498, near M 49; Figure 2-31
81°	320	II 148	4612	191	13 Apr. 1784	Vir	11.5	and sw 560; II 20, near M 49; Figure 2-33
87°	1350	II 540	5831	532	24 Feb. 1786	Vir	11.5	
90°	11	II 6	-	47	18 Dec. 1783	Cet	-	2 stars

Table 6-4: Nine objects are missing in the *Zone Catalogue*; all are galaxies (three were involved in the M 49 puzzle).

The unpublished *Zone Catalogue* might have been seen by a few people only. Dreyer assumed that John "shared the universal opinion at the time, that very few of his father's nebulae could be seen, or at least, usefully observed with any but the largest telescopes; but chiefly because he always intended to bring out a General Catalogue of all known Nebulae and Clusters, a task which the vast amount of valuable work he carried out did not allow him to complete till 1864."[1057] David Brewster wrote of the *Zone Catalogue* as "a work of immense labour [and] an extraordinary monument of the unextinguished ardour of a lady of seventy-five in the cause of abstract science".[1058] Caroline sent a copy to Gauss at Göttingen on 8 September 1825, who replied on the 28th that it "shall always be considered as the greatest ornament of the library of our Observatory".[1059] The present author recently published Caroline's *Zone Catalogue* for the first time. His website offers a revised, digital version.

On 8 February 1828, 77-year-old Caroline received the *Gold Medal* of the *Astronomical Society of London* for her work on the *Zone Catalogue*. The laudation was written and held by the Vice-President James South:[1060]

Gentlemen, –

Our excellent president, in his address, has informed you of the appropriation of two of our gold medals since our last anniversary: a third, however, has been decreed by your council; and when it is

known that Miss Caroline Herschel is the individual to whom it stands adjudged, it is not difficult to determine why the president has avoided the slightest allusion to it. But that your Council has not selected one from the many of its members infinitely more competent to do justice to the transcendent merits of that illustrious lady is most assuredly matter of regret. I must therefore throw myself upon your indulgence, hoping that the goodness of the cause may in some measure compensate for the inability of its advocate.

The labours of Miss Herschel are so intimately connected with, and are generally so dependent upon, those of her illustrious brother, that an investigation of the latter is absolutely necessary ere we can form the most remote idea of the extent of the former. But when it is considered that Sir W. Herschel's contributions to astronomical science occupy sixty-seven memoirs, communicated from time to time to the Royal Society, and embrace a period of forty years, it will not be expected that I should enter into their discussion. To the Philosophical Transactions I must refer you, and shall content myself with the hasty mention of some of her more immediate claims to the distinction now conferred. To deliver an eulogy (however deserved) upon his memory is not the purpose for which I am placed here.

His first catalogue of new nebulae and clusters of stars, amounting in number to one thousand, was made from observations with the twenty-foot reflector in the years 1783, 1784, and 1785. A second thousand was furnished by means of the same instrument in 1785, 1786, 1787, and 1788; while the places of 500 others were discovered between 1788 and 1802. But when we have thus enumerated the results obtained in the course of sweeps with this instrument, and taken into consideration the extent and variety of the other observations which were at the same time in progress, a most important part yet remains untold. Who participated in his toils? Who braved with him the inclemency of the weather? Who shared his privations? A female. Who was she? His sister. Miss Herschel it was who by night acted as his amanuensis: she it was whose pen conveyed to paper his observations as they issued from his lips; she it was who noted the right ascensions and polar distances of the objects observed; she it was who, having passed the night near the instrument, took the rough manuscripts to her

cottage at the dawn of day and produced a fair copy of the night's work on the following morning; she it was who planned the labour of each succeeding night; she it was who reduced every observation, made every calculation; she it was who arranged everything in systematic order; and she it was who helped him to obtain his imperishable name.

But her claims to our gratitude end not here; as an original observer she demands, and I am sure she has, our unfeigned thanks. Occasionally her immediate attendance during the observations could be dispensed with. Did she pass the night in repose? No such thing: wherever her brother was, there you were sure to find her. A sweeper planted on the lawn became her object of amusement; but her amusements were of the higher order, and to them we stand indebted for the discovery of the comet of 1786 [1st], of the comet of 1788 [2nd], of the comet of 1791 [5th], of the comet of 1793 [6th], and of the comet of 1795 [7th], since rendered familiar to us by the remarkable discovery of Encke [8th]. Many also of the nebulae contained in Sir W. Herschel's catalogues were detected by her during these hours of enjoyment. Indeed, in looking at the joint labours of these extraordinary personages, we scarcely know whether most to admire the intellectual power of the brother, or the unconquerable industry of the sister.

In the year 1797 she presented to the Royal Society a Catalogue of 560 stars taken from Flamsteed's observations and not inserted in the British Catalogue, together with a collection of errata that should be noticed in the same volume.

Shortly after the death of her brother, Miss Herschel returned to Hanover. Unwilling, however, to relinquish her astronomical labours whilst anything useful presented itself, she undertook and completed the laborious reduction of the places of 2,500 nebula, to the 1st of January, 1800, presenting in one view the results of all Sir William Herschel's observations on those bodies, thus bringing to a close half a century spent in astronomical labour.

For this more immediately, and to mark their estimation of services rendered during a whole life to astronomy, your Council resolved to confer on her the distinction of a medal of this Society. The peculiarity of our President's situation, however, and the earnest

manner in which the feelings naturally arising from it were urged when the subject was first brought forward, caused your Council to pause, and waive on that occasion the actual passing their proposed vote. The discussion was, however, renewed on Monday last, and, although there was every disposition to meet the President's wishes, still under a conviction that the actual doing so would have been a dereliction of public duty, it was Resolved unanimously, " That a Gold Medal of this Society be given to Miss Caroline Herschel, for her recent reduction, to January, 1800, of the Nebule discovered by her illustrious brother, which may be considered as the completion of a series of exertions probably unparalleled either in magnitude or importance in the annals of astronomical labour." This vote I am sure every one whom I have the honour to address will most heartily confirm.

Mr. Herschel, in the name of the Astronomical Society of London, I present this medal to your illustrious aunt. In transmitting it to her, assure her that since the foundation of this Society, no one has been adjudged which has been earned by services such as hers. Convey to her our unfeigned regret that she is not resident amongst us; and join to it our wishes, nay our prayers, that as her former days have been glorious, so her future may be happy.

Figure 6-2: Caroline’s *Gold Medal*, awarded by the *Astronomical Society of London* for her astronomical work, especially the compilation of the *Zone Catalogue*.[1061]

6.2. John Herschel's Slough/Cape observations and the work of Lord Rosse

William Herschel's catalogues, though receiving praise, were hardly used for subsequent observations. It was John's work that kept things going.[1062] He was instructed by his father to continue the astronomical work in a document, titled "Work to be done".[1063] John's observational career started on 12 October 1816.[1064] He re-examined some of William's double stars with the 7-ft and observed Messier objects. A profound double star campaign was started in early 1821, together with James South.[1065] The observers used a fine equatorial Tully refractor of 5 feet focal length and 3.75 inches aperture, purchased by South and erected in his private observatory at Campden Hill, London. The results, describing 380 cases, were published in the *Philosophical Transactions* of 1824.[1066]

William's instructions also concern sweeping: "To finish the Sweeps of the heavens" and "To make new Sweeps of the heavens". In the years 1825–33, John reproduced and extended his father's observations. At Slough he used a Herschel-type front-view reflector with an 18¼-inch mirror of 20 feet focal length, completed in 1820 (Figure 6-3). Two mirrors were made, one by William alone and another one cast and ground under his supervision. The instrument was erected in front of Caroline's cottage, at the place of the old 20-ft (see Figure 2-123).

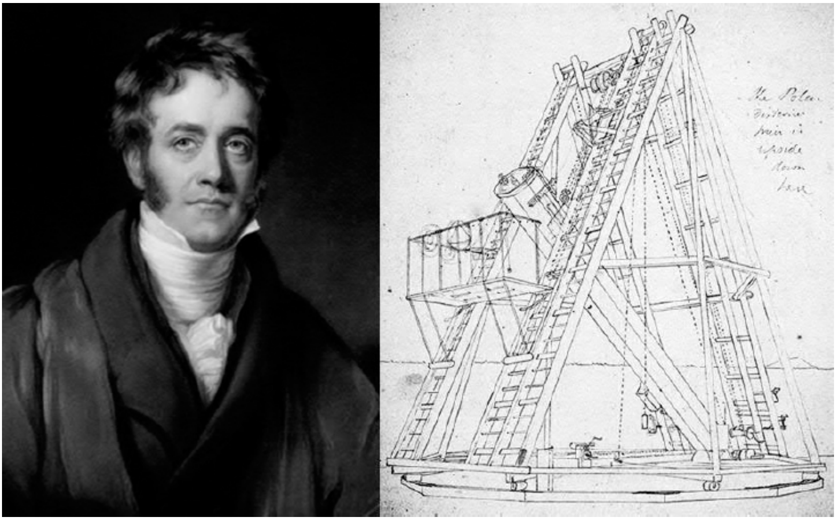
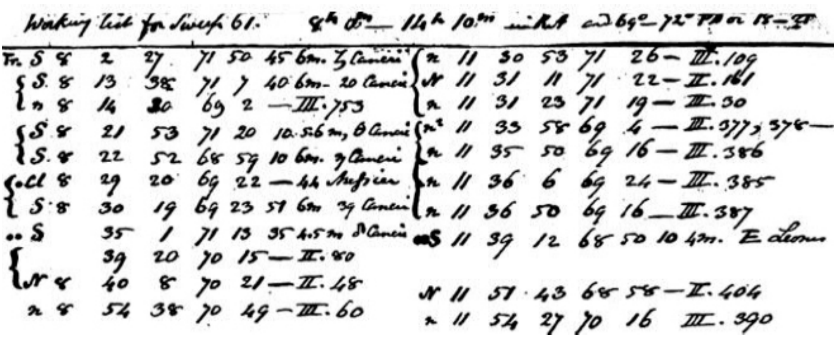


Figure 6-3: John Herschel (1792–1871) and his 20-ft / 18¼-in front-view reflector, completed at Slough in 1820.1067

When John started observing, his intention was not the discovery of new non-stellar objects, but a careful examination of the three Herschel catalogues. The main goal was the identification of objects and the determination of reliable absolute positions (coordinates). To realise this ambitious project, he compiled 'working lists', which should direct his sweeps (Figure 6-4).1068 They were based on Caroline's *Zone Catalogue*. In autumn 1825, after performing about 20 sweeps, he wrote to his aunt in Hanover:1069 "I have already found your Catalogue of nebulae in zones very useful in my twenty-foot sweeps, and I mean to get it in order for publication by degrees; but it will take a long time, as it will require a great deal of calculation to render it available as a work of reference."



Working list for Sweep 61. 8h 0m — 14h 10m in RA and 69°–72° PD or 18–21

Fr. S	8	2	27	71	50	45 6m. ζ Cancri
S.	8	13	38	71	7	40 6m. 20 Cancri
n	8	14	30	69	2	— III. 753
S	8	21	53	71	20	10. 5.6m, θ Cancri
S.	8	22	52	68	59	10 6m. η Cancri
•Cl	8	29	20	69	22	— 44 Messier
S	8	30	19	69	23	57 6m 39 Cancri
•• S		35	1	71	13	35 4.5m δ Cancri
		39	20	70	15	— II. 80
N	8	40	8	70	21	— II. 48
n	8	54	38	70	49	— III. 60

n	11	30	53	71	26	— III. 109
N	11	31	11	71	22	— II. 161
n	11	31	23	71	19	— III. 30
n²	11	33	58	69	4	— III. 377, 378 —
n	11	35	50	69	16	— III. 386
n	11	36	6	69	24	— III. 385
n	11	36	50	69	16	— III. 387
•• S	11	39	12	68	50	10 4m. ε Leonis
N	11	51	43	68	58	— II. 404
n	11	54	27	70	16	III. 390

Figure 6-4: John Herschel's 'Working list for Sweep 61', made on 23 March 1827.

Two test sweeps with the new 18¼-in reflector were already made on 29/30 May 1821 (later counted as sweep 53 and 54); Caroline was present. John's first observed non-stellar objects were two of his father's, the galaxies NGC 5470 (II 538) and NGC 5845 (III 511) in Virgo, followed by the globular cluster M 5 in Serpens. Eight regular sweeps were performed from May to November 1823 (sweep 43–49 and sweep 1). Sweeps 43–48 were first called 1114–19, continuing the numbering of his father, who had made a last sweep (1113) on 31 May 1813. Sweep 48 brought the first object after William's final discovery (1802); it was the galaxy NGC 7010 in Aquarius. A month later, Karl Ludwig Harding found the famous Helix Nebula NGC 7293 in the same constellation. Table 6-5 shows the first 10 post-William objects. On 18 June 1825, Wilhelm Struve interrupted John's dominance, when discovering the planetary nebula NGC 6752 in Ophiuchus. He also found NGC 629 and NGC 6648 in that year, but these are only a star group in Cassiopeia (Auwers 16) and a star pair in Draco (Auwers 41). All three were later listed by Auwers in his 'list of new nebulae' (see next section).

Date	NGC	h	Discoverer	Tel	Con	Type	V	Remarks
6 Aug. 1823	**7010**	2100	J. Herschel	18.3 Rl	Aqr	Gx	13.0	
Sep. 1823	**7293**	-	Harding	8.5 Rl	Aqr	PN	7.3	Helix Nebula, Auwers 48
2 Nov. 1823	**7653**	2237	J. Herschel	6.2 Rr	Peg	Gx	12.7	
11 Apr. 1825	**4178**	1125	J. Herschel	18.3 Rl	Vir	Gx	11.4	
9 May 1825	**5666**	1834	J. Herschel	18.3 Rl	Boo	Gx	12.9	
21 May 1825	**6785**	2038	J. Herschel	18.3 Rl	Aql	PN	12.3	NGC 6778
18 Jun. 1825	**6572**	2000	W. Struve	9.6 Rr	Oph	PN	8.1	
7 Sep. 1825	**6995**	2093	J. Herschel	18.3 Rl	Cyg	SNR		Veil Nebula (part)
7 Oct. 1825	**7703**	2251	J. Herschel	18.3 Rl	Peg	Gx	13.4	
7 Oct. 1825	**7772**	2276	J. Herschel	18.3 Rl	Peg	OC		

Table 6-5: The first ten non-stellar objects, found after William Herschel in 1802. Most are due to John, using the 18¼-in reflector (h = number in his *Slough Catalogue*). NGC 7653 was seen with the Tully refractor while observing M 71.

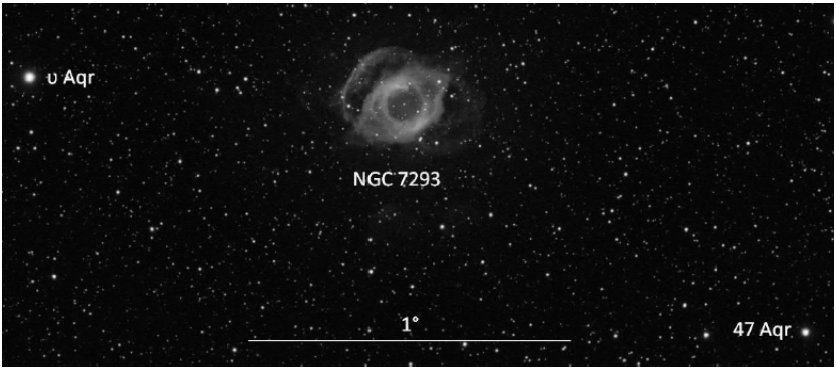


Figure 6-5: The Helix Nebula NGC 7293 in Aquarius, found by Harding in September 1823, was never seen by William, though he observed the two labelled stars on 13 October 1786 (sweep 609). He again crossed the region on 11 November 1787 (sweep 754). John never observed the large nebula, filling the field of view, though he later catalogued it as GC 4795.

In 428 sweeps, John could observe a large fraction of his father's objects (Table 6-6).1070 Their data were confirmed, supplemented and corrected. Moreover, he found 510 new objects. The results were published in 1833 as 'Observations of nebulae and clusters of stars, made at Slough, with a twenty-feet reflector, between the years 1825 and 1833' in volume 123 of the *Philosophical Transactions*.1071 The *Slough Catalogue* has 2307 entries. The publication contains 67 drawings of non-stellar objects.

Objects found by	Number
William Herschel	1690
John Herschel	510
Caroline Herschel	9
observers prior to Herschel (Messier etc.)	91
observers later than Herschel (W. Struve)	4

Table 6-6: Content of John Herschel's *Slough Catalogue*, published 1833.

John's work meant real progress and became a great success, which

was due to remarkable new features: coordinates for 1830, AR order and object numbers (h); this became the new standard. The great homogeneity rests on the fact that all objects were observed and measured by him with the same telescope, being in a perfect condition from the start.

From 1834 to 1838 John continued his observations of nebulae and star clusters in Feldhausen near the Cape of Good Hope with his 18¼-inch reflector (Figure 6-6).[1072] Additionally, he used Caroline's large sweeper. His mission was the exploration of the southern sky, which led to the discovery of 1200 non-stellar objects. 382 sweeps were made. Eight years earlier, James Dunlop had done important preliminary work at Paramatta, near Sydney.[1073] John did not appreciate it very much, having problems with the identification of Dunlop's objects.

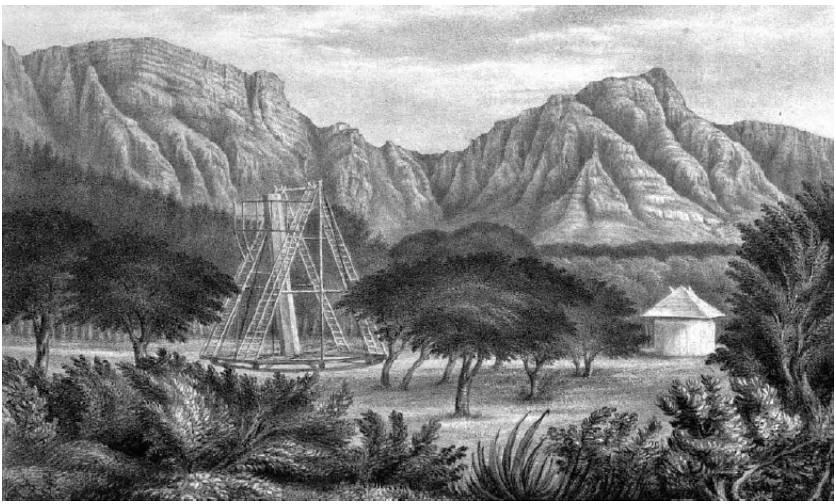


Figure 6-6: John Herschel's observing site at Feldhausen (latitude -34°, longitude 18.5° E) and the 18¼-in reflector.[1074]

John's observations of southern objects appeared not until 1847, titled 'Results of astronomical observations made during the year 1834, 5, 6, 7, 8 at the Cape of Good Hope; Being the completion of a telescopic survey of the whole surface of the visible heavens, commenced in 1825'.[1075] The delay was due to his many duties after his return to England and the task of processing the vast amount of information. The main part of the massive book is the

Cape Catalogue, which has 1717 entries (Table 6-7). Some observations were made in regions still visible for William (see Table 2-51). Astonishingly, John's most northern objects are at +16° declination in Leo.[1076] In the overlapping sky zone, he discovered 237 non-stellar objects. The brightest is the open cluster NGC 2520 (h 3112) in Puppis (6.5 mag) at -28°.

Objects found by	Number
John Herschel	1200
William Herschel	204
Caroline Herschel	2
Dunlop	269
other observers (Messier etc.)	48

Table 6-7: Content of John Herschel's *Cape Catalogue*, published 1847.

Like its forerunner, the *Cape Catalogue* was a great success and John's scientific reputation reached another climax. In fact, he was the only astronomer in history who visually examined the entire sky with a large telescope. Moreover, at Feldhausen he made careful delineations of 99 southern nebulae and star clusters.[1077] A central goal, following the ideas of his father, was to proof the claimed evolutionary transition from the nebula to the star cluster. Due to his comprehensive observations and theoretical work, he definitely became the dignified successor of William Herschel (see section 4.1.6). John's work also contains observations of double stars, Saturn, sunspots and Comet Halley, watched in 1838 (see Figure 3-40).

John Herschel's final work, the 'Catalogue of nebulae and clusters of stars', commonly known as the *General Catalogue* (GC), was published 1864 in volume 154 of the *Philosophical Transactions*.[1078] At that time he was already 71. After years of low astronomical activity, he had decided to collect all known nebulae and star clusters in a common catalogue. The compilation of the GC started about 1859 and was finished on 23 June 1863.[1079]

John's *General Catalogue* differs from his *Slough Catalogue* and *Cape Catalogue*, which were mainly based on his own observations. His late work presents all non-stellar objects, found until 1863 in both

hemispheres. It includes those, discovered by the Birr Castle astronomers, d'Arrest at Copenhagen Observatory and others.[1080] Therefore, it is a 'database' in the modern sense. Concerning the 2500 nebulae and star clusters catalogued by William, the *General Catalogue* is the final revision, made by a Herschel family member. It has 5079 entries. In 1878 Dreyer published a 'GC supplement' with 1172 entries. However, the number of deep-sky objects found by a host of international observers increased steadily. Pressure grew on Dreyer, the recognized authority in the field, to create a completely new catalog (instead of a 'second GC supplement'). Finally, he was urged by the RAS to compile a *New General Catalogue*, which was finally published in 1888.[1081]

Objects found by	Number
William Herschel	2510
John Herschel	1717
Caroline Herschel	10
Birr Castle observers	265
Dunlop	272
d'Arrest	102
other observers	203

Table 6-8: Content of John Herschel's *General Catalogue*, published 1864.

A major contribution to the *General Catalogue* were the objects, found at Birr Castle. In the nineteenth century, this place in central Ireland was among the most important centres for visual observations of nebulae and star clusters. Its figurehead was the 'Leviathan of Parsonstown'. The 72-inch Newtonian of 54 feet focal length was operational in 1845; for a long time, it was the largest telescope in the world. Its creator, William Parsons, the 3rd Earl of Rosse (known as Lord Rosse), was a multi-talented man like William Herschel (Figure 6-7). As an engineer of great skill, he naturally was inspired by the large reflectors, constructed by the eminent ethnic German astronomer. Lord Rosse mastered the complicated processes like no other – from casting the metal mirror to the telescope's optical and mechanical design. Already in April 1845, the new 72-inch brought an epochal discovery: the spiral structure of M 51 in Canes Venatici (see Figure 2-58).[1082]

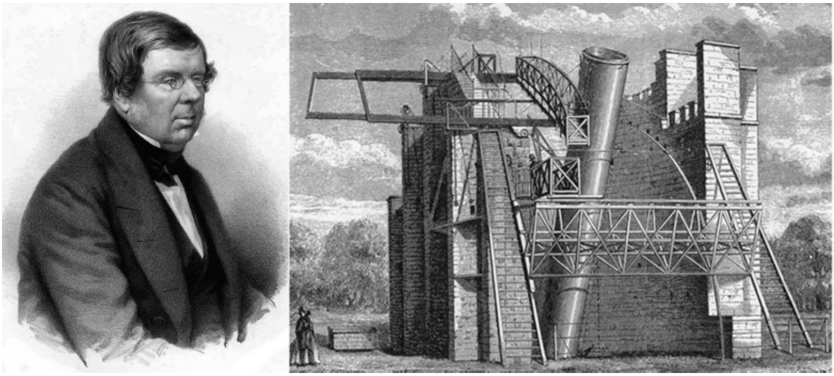
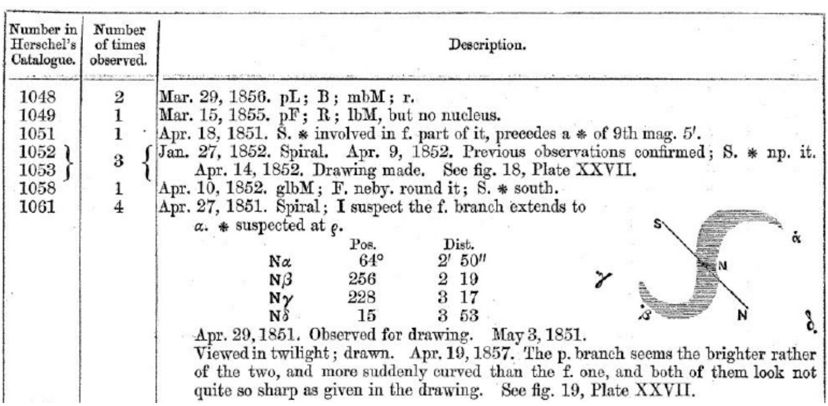


Figure 6-7: William Parsons, 3rd Earl of Rosse (known as Lord Rosse), and his 72-inch reflector, erected 1845 at Birr Castle.

Together with his talented scientific assistants, the Irish nobleman observed bright or otherwise remarkable nebulae to reveal their structure and nature. The large reflector was the ideal tool. Lord Rosse selected his targets from John Herschel's *Slough Catalogue*. The observing campaign started in 1848. First results, including impressive drawings of nebulae, were published in the *Philosophical Transactions* of 1861 (Figure 6-8).1083 A second and much more comprehensive paper appeared in 1880, published by Lord Rosse's son Lawrence Parsons.1084 It was essentially the work of Dreyer, 1874–78 scientific assistant of the 4th Earl of Rosse. It contains a large amount of observations, made between 1848 and 1878 (Table 6-9).



Number in Herschel's Catalogue.	Number of times observed.	Description.
1048	2	Mar. 29, 1856. pL; B; mbM; r.
1049	1	Mar. 15, 1855. pF; R; lbM, but no nucleus.
1051	1	Apr. 18, 1851. S. ✻ involved in f. part of it, precedes a ✻ of 9th mag. 5′.
1052 } 1053 }	3	Jan. 27, 1852. Spiral. Apr. 9, 1852. Previous observations confirmed; S. ✻ np. it. Apr. 14, 1852. Drawing made. See fig. 18, Plate XXVII.
1058	1	Apr. 10, 1852. glbM; F. neby. round it; S. ✻ south.
1061	4	Apr. 27, 1851. Spiral; I suspect the f. branch extends to α. ✻ suspected at ρ. Pos. / Dist.: Nα 64° 2′ 50″; Nβ 256 2 19; Nγ 228 3 17; Nδ 15 3 53. Apr. 29, 1851. Observed for drawing. May 3, 1851. Viewed in twilight; drawn. Apr. 19, 1857. The p. branch seems the brighter rather of the two, and more suddenly curved than the f. one, and both of them look not quite so sharp as given in the drawing. See fig. 19, Plate XXVII.

Figure 6-8: Lord Rosse's 1861 publication. The sketch shows the

10.2 mag 'spiral nebula' NGC 4051 (h 1061) in Ursa Major, found by Herschel on 6 February 1788 (sweep 810), catalogued as planetary nebula IV 56 with an 'extensive chevelure'.

Data	Number	Remarks
objects	1840	1711 from *Slough Catalogue*
observations	3234	1848–78; mainly with 72-inch
sketches	255	in the descriptions
drawings	39	on separate tables
observers	11	W. & L. Parsons, assistants

Table 6-9: Content of the Birr Castle publication of 1880, compiled by Dreyer and published by Lawrence Parsons.

In the middle of the 19th century, Herschel objects were popularized by the books of two eminent British authors. The year 1844 saw the publication of a famous guide for amateur astronomical observations: the two-volume *Cycle of Celestial Objects* by William Smyth.1085 Volume 1, titled *Prolegomena*, is an introduction to practical astronomy. Volume 2 is the famous *Bedford Catalogue*, a compendium of observations with a 5.9-inch Tully refractor at his private Bedford Observatory. It treats a selection of nebulae and star clusters from the catalogues of William and John Herschel, Charles Messier and Wilhelm Struve. The work was both praised and criticised. Undisputed is its great influence on amateur astronomers, among them Thomas Webb, who published his popular book *Celestial Objects for Common Telescopes* in 1859. It is a comprehensive guide to stars, nebulae and star clusters, taken from the catalogues of Messier and Herschel.1086 No doubt Smyth and Webb had spotted a gap in the market, since professional astronomers usually did not popularise their observations.

6.3. Auwers' revision, d'Arrest's observations and position accuracy

In 1850 another German version of Herschel's catalogues was published by Wilhelm Pfaff.1087 Unfortunately, the number of

errors was even larger than in Bode's work. Auwers remarked about Pfaff's attempt: "The situation was insofar awkward, as the publication was defaced by a large number of errors – the position data contain around 350."[1088] D'Arrest also criticised this work, judging it as a "very erroneous reprint of the unreduced nebulae catalogues".[1089]

Inaccurate or even incompetent handling of data, as Bode and Pfaff did, was not the business of the German astronomer Arthur Auwers (Figure 6-9). Later called the 'Pope of astrometry', he pushed the position measurement to the limit. His revision of the Herschel catalogues was published in 1862, titled 'William Herschel's Verzeichnisse von Nebelflecken und Sternhaufen'.[1090]

Auwers started his work in 1854, at the early age of 16 (Figure 6-9). The ambitious project was triggered by his friend Friedrich Winnecke, who had "just tackled [an] excerpt of the [John] Herschel catalogues contained in the Phil. Trans. and the Cape sojourn for private use."[1091] A key event was Auwers' observation on 21 January 1854 of the large, faint galaxy NGC 6946 (IV 76) in Cygnus (see Figure 3-8). Due to the surprising visibility in a 7.4 cm Merz comet-seeker, he decided "to include also those faint nebulae, estimated by Herschel to have diameters of several arcminutes […] later experience has taught me that I have added with it nothing superfluous to the excerpt".

Auwers was not only interested in a 'clean' catalogue, free of incorrect data or identical entries, his ambitions were also driven by astrometry. The revision offered the chance to get proper motions, by comparing current places with those, determined half a century ago. Alas, the data situation was not advantageous: "Due to the nearly complete lack of literature, I could not use the Phil. Trans. for my reductions."[1092] Auwers' only source was the second edition of Pfaff's book on Herschel of 1850, offering unreliable catalogue data.

When the young student of Göttingen University eventually had access to Herschel's publications, the results could be checked.[1093] Auwers was quite sure that the data "were brought into complete accordance with the Philosophical Transactions by repeated comparison and correction". For him, John Herschel's catalogues

were of great value too, though he "often detected large differences, whose reason I cannot explain". Because the Slough observations were based on the *Zone Catalogue*, Auwers suggested: "perhaps Miss Caroline's reduction is based in many cases on other observations but those published". He checked the reference stars against Francis Baily's *British Association Catalogue* (BAC), the only star catalogue available in Göttingen, detecting a number of wrong designations.[1094] Most errors were due to incorrect identifications or problems with reference stars.

Auwers determined new coordinates for 1830, the equinox of the *Slough Catalogue*. Afterwards the Herschel objects were (for the first time) sorted by right ascension. Early March 1856, he sent a copy of his manuscript to his friend Winnecke in Berlin. Later (in the publication of 1862) he proffered for his "active support [the] most vivid thank".[1095]

About the same time, Heinrich d'Arrest, assistant at Leipzig Observatory and 16 years older than Auwers, checked parts of the Herschel catalogues (both men are shown in Figure 6-9). The Danish-born astronomer was also interested in proper motions, criticising the work of Bode and Pfaff. But there are differences from Auwers: his task was based on observations; 366 objects of class I ('bright nebulae') and IV ('planetary nebulae') were treated.

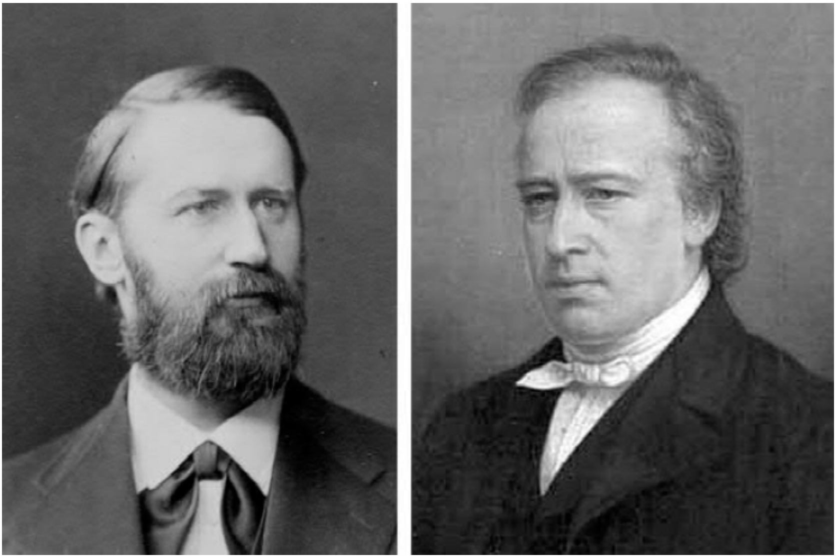


Figure 6-9: Advocates of astronomical precision: Arthur Auwers (left) and Heinrich d'Arrest.

D'Arrest published the results in 1856.[1096] He was not aware of Auwers' work at that time. The same applies vice versa, as Auwers later remarked:[1097]

When d'Arrest's work appeared, the complete reduction dunned by him was just finished, I had seen the need of such a task already in 1854; his wish, stated in his publication and supported by others, and the growing interest about nebulae during the last years, now induces me to use the opportunity, offered by Prof. Luther, to publish the reduced catalogue in the XXXIV. Abtheilung of the Königsberg Observations, to give this work to the astronomers, which was primarily made for private use.

Auwers' publication is dated 15 December 1861. Since autumn 1859 he assisted Eduard Luther at Königsberg, who wrote in the preface:[1098]

Mr. A. Auwers, currently assistant at this observatory, already feeling the need for a complete reduction of William Herschel's observations of nebulae in 1854, initially realised this task for private use only. As now this highly meritorious work is suitable to remove the difficulties caused by the arrangement of the nebulae and star clusters in W. Herschel's three catalogues of the years 1786, 1789 and 1802 and hampering their practical use, an issue not being essentially improved by the existing revisions, I will present this editing of Herschel's observations of nebulae, meeting the wishes of several colleagues, as an appendix to the Königsberg Observations, together with the necessary preliminary remarks by Mr. Auwers.

In Auwers' catalogue the Herschel objects are sorted by AR (for 1830). The first column gives the class designation; the descriptions were copied from the original. Then the coordinate differences between William (H) and John (h) are given. Column 'Synonym' shows cross-identifications to the *Slough Catalogue* (h) and those of d'Arrest, Laugier, Messier, Lacaille and Dunlop. 'Obs' lists the number of William's observations. Figure 6-10 presents the beginning of the table, extending over 38 pages. Auwers thought it

to be “far more comfortable than the cumbersome transcription by Pfaff”.1099

Nro.	R. A. h m s	Decl. ° ′	Description.	H. - h. Δα s	Δδ ′	Synonym. h.	Other Cat.'s	Obs.
II. 591.	0 0 0	+ 14 52	F; p L; i fig; unequally B.	- 4	- 1	3		1
III. 866.	0 0 7	+ 32 27	v F; v S; the np corner of a square. . .	+ 4	- 2	2		1
III. 147.	0 0 10	+ 24 59	2 or 3 * with seeming nebulosity. . . .					1
III. 461.	0 1 22	— 25 58	v F; c L; l E; g l b M; 4 or 5′ l. . . .	+ 7	- 3	2308		1
IV. 15.	0 1 42	+ 26 48	A F * with S chevelure and 2 burrs. . .	. . .	+ 3	5		1
II. 853.	0 2 6	+ 32 23	F; S; E near mer.	+ 7	- 1	6		1
III. 861.	0 3 17	+ 30 6	c F; S.	- 17	0	7		1
III. 456.	0 3 41	+ 5 27	v F; p S; i fig.					1
IV. 58.	0 4 17	+ 71 35	* 9m surrounded with v F milky neb. The * is either D or not R. Less than 1′ d. . .	+ 22	0	8		1

Figure 6-10: The first entries in Auwers’ revised Herschel catalogue, giving coordinates for 1830 (see text).

Auwers also listed catalogue errors: 32 by William and 115 by John. Additionally, there are notes for individual objects, a table of discovery dates and an object index, arranged by class and running number. He completed the publication with William Herschel’s list of 52 regions with ‘extensive diffused nebulosity’ (see Table 4-7).1100 For the first time, coordinates and descriptions of these obscure objects were made accessible for the German reader.

Of special importance are the appendices, containing revisions of the catalogues of Messier and Lacaille.1101 Auwers reduced the positions to 1830 and sorted the objects by right ascension. Curiously, Messier’s last entries, M 102 and M 103, are missing.1102 Perhaps the most interesting appendix is the ‘Verzeichnis neuer Nebelflecke’ (‘List of new nebulae’) with 50 entries (see Table 6-5). Except for two, it shows all objects discovered from 1824 to 1862 and not already contained in the catalogues of William and John.1103 Again, the positions are given for 1830.

Auwers live-long claim was accuracy. Thus, it was natural to get information about the mean positional error of Herschel’s positions, derived from the reference stars. Of course, this was an issue, Herschel himself was already interested in. He had considered four periods, according to improvements of his instrument and measuring methods. Auwers remarked: “The imperfect device and the whole mounting of the large telescope made it impossible to achieve a sufficient accuracy for the original positions.”1104 Although John Herschel had observed many objects of his father to

get better positions, there were still a great number, which remained unverified. Auwers wrote: “Most of all, the publication of the original observations is desired for the sake of the remaining 650 nebulae; a large fraction of these objects is faint, thus our knowledge about their places might be limited for a long to [William] Herschel’s determinations”.1105

Today, Herschel’s object positions can be checked against modern measurements. However, this requires a thorough identification, as performed by the author. The result slightly differs from the examination by William Herschel and Auwers (Table 6-10); curiously, the latter generally was a bit too optimistic.1106

	Difference in AR			Difference in PD		
Period	Herschel	Auwers	Steinicke	Herschel	Auwers	Steinicke
before December 1783	60^s	-	-	9'	-	-
end of 1783 – end of 1784	30^s	8.3^s	17.5^s	4.5'	1.45'	3.1'
end of 1784 – September 1785	11^s	5.9^s	10.3^s	3.5'	1.25'	1.9'
remaining time until 1802	5^s	4.8^s	8.7^s	2'	1.05'	2.2'

Table 6-10: Accuracy of the catalogue positions, according to William Herschel, Auwers and the author (AR in ^{s} for comparison with Herschel and Auwers). There were only a few objects found before December 1783; Herschel’s values are rough estimates.

Selection	ΔAR (')	ΔPD (')
catalogue I	3.8	2.6
catalogue II	2.0	1.8
catalogue III	2.6	2.3
PD > 30°	2.8	2.1
PD ≤ 30°	3.7	4.2
south meridian	2.7	2.2
north meridian	3.2	2.9
eastern sweeps	7.5	1.3

Table 6-11: Position accuracy for selected cases: catalogues, large/small PD and telescope orientation.

The investigation was also done for the three catalogues separately, now using equal units (Table 6-11). Of course, the larger errors for Herschel’s first catalogue are due to technical and methodical deficiencies in the early period. The second gives the best positions.

Why are they worse for the third? The simple explanation: many more areas with small PD (pole region) were observed. Here the accuracy is lower due to the special setting of the telescope, oriented to the north. Of course, the eastern sweeps had the greatest problems (the determination of positions was much more difficult). In 1863, a review of Auwers' work appeared in the *Monthly Notices of the Royal Astronomcal Society*.1107 The anonymous writer states: "The absolute positions have been previously calculated by Bode and Caroline Herschel, and more recently as to two of the eight classes by D'Arrest, but a new and complete reduction of the observations appeared very desirable, and Mr. Auwers has now availed himself of the opportunity given to him by Prof. Luther for the publication in the *Königsberg Observatory Memoirs* of the results calculated by him originally for his own use, about seven years ago."

In Copenhagen, d'Arrest planned to observe all nebulae of William and John Herschel's catalogues, visible in the 11" Merz refractor (Figure 6-11). His aim was not only a revision but also getting reliable data for proper motions by measuring absolute positions. Obviously, his ambitious task was inspired by the mechanical and optical quality of his equatorial refractor, which "shows all Herschel nebulae, even the most difficult".1108 D'Arrest valued it "exactly in the middle between Herschel's 20-ft reflectors in their best condition". He omitted all objects of class VI, VII and VIII (star clusters), interpreted as mere accumulations of stars, essentially different from the nebulae. Moreover, he rated theses classes as arbitrary and unnatural, because he had noticed that in regions of the Milky Way there are many similar objects, often near to a catalogued one, not considered by Herschel.

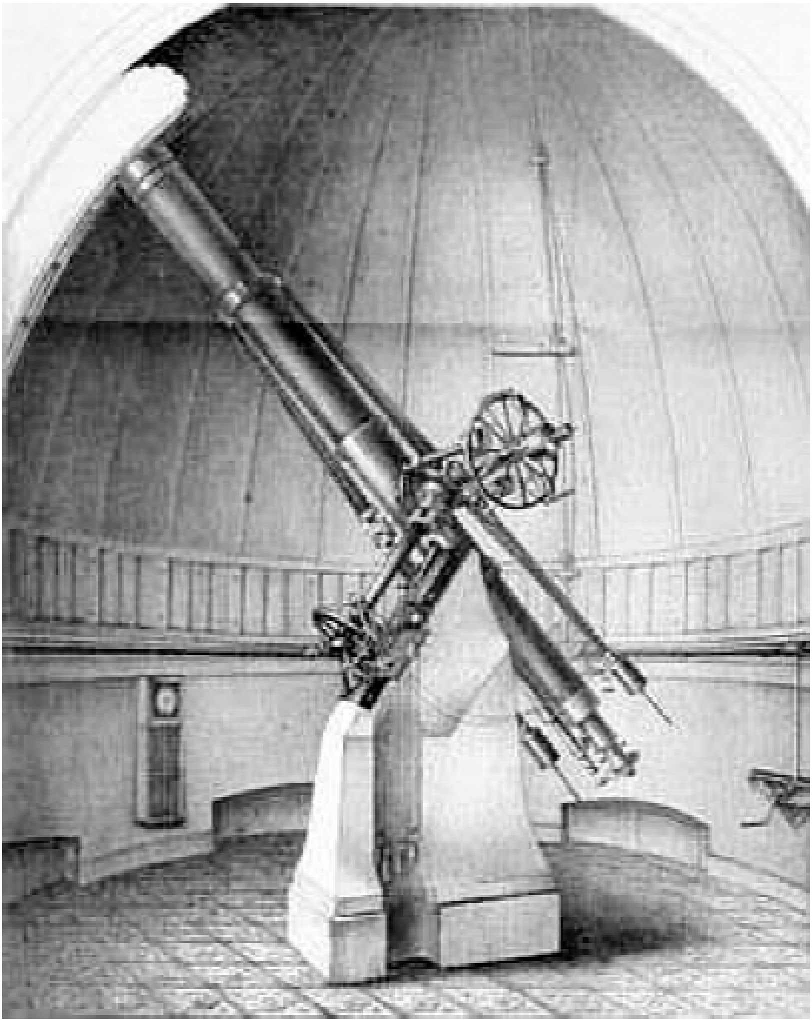


Figure 6-11: Heinrich d’Arrest’s excellent equatorial 11-inch Merz refractor, erected in 1861 at Copenhagen Observatory.[1109]

Unfortunately, d’Arrest’s ambitious plan could not be completed. After five and a half years (October 1861 to May 1867) quite a number of objects were still unobserved. The main reasons: bad weather, lack of time and his decreasing health. He therefore decided to terminate the campaign and to publish the achieved results. In 1867, they appeared in Copenhagen as *Siderum Nebulosorum Observationes Havnienses*.[1110] The 415-page monograph

was completely written in Latin – hardly conventional at that time. The publication contains 1942 non-stellar objects, among them 308 new ones.

Usually, each object was observed several times (Figure 6-12). The tabular data list about 4800 observations, from which accurate positions for 1861 were determined. Of course, neither Auwers nor d'Arrest were able to measure any proper motions. Mainly this was due to the studied objects (mainly galaxies), which show no proper motion. However, this fact was not known at the time. Both astronomers attributed their failure to the inaccurate positions, determined by William and John Herschel with instruments (alt-azimuthally mounted reflectors), not meeting the current high standards (equatorial refractors).

Senioris Herschelii clas. et num.	Junioris Herschelii observat. nebular.	Asc. Rect. media 1861.	Declinatio media 1861.	Nebulosarum facies et indoles.	Nox.
...	...	11h 55m 37s	+ 2° 30',5 45	Rotunda; non utique parva. Secundae classi adscribenda. Efficit triangulum cum 2 fixis 13 et 16 ord. australioribus, quarum illa seq. nebulam per 6s,6. — Novarum mearum 131ma in Actis Astronom 1500; attamen quaestio adhuc est, an sit h. 1057 = H. II. 276 cum errore 15' in declinatione	102
II. 741	1058	11 55 44	+ 49 25,0	Satis forte lumen exhibens; nucleus rotundus. * 13 magn. praec. 21s,3 ad austrum	6
		55 45	24,7	Luminosa, rotunda, cometaris; pedetentim clarior meditullium versus. 40" aut 45". * 12 magn. antecedens 21s,6 quasi 1' ad meridiem. — Neb n. 1788 tantum „pretty faint"; apud Herschelium II non inepte „bright"	375
IV. 56	1061	11 56 4	+ 45 18,5	Nucleolus = * 13 hon. (dissolvitur in compluscula puncta lucida) cum halitu circumfuso, grandi, ovali. * 10 magn. praec. 13s,1 32" ad meridiem. Cum eadem fixa comparavit nebulam a. 1865 Cl. Rümkerus II (Acta Astronom. vol. LXVI pag. 90). Caeterum obvia in Argelandri Perlustratione Coeli Borealis	274
...	...	11 56 4	+ 20 30,0	Longula, licet perpusilla ac perobscura. * 18 magn. praec. 7s in eodem proxime parallelo. — Antecessorum Catalogi nullam neb in his tractibus afferunt	181
		56 4	29,8	Pusilla; circulariter terminata. Confirmata etiam amplificationibus 231 et 365	180
		56 5	29,3	Opaca, minuta, oblonga; inter plures stellulas minutissimas. * 10 ord. seq. 3s,0 5' ad austrum	173

Figure 6-12: Part of d'Arrest's *Siderum Nebulosorum*. The galaxy IV 56 (NG 4051) in Ursa Major was observed four times (May 1864 and May 1865); it is one of Lord Rosses 'spiral nebulae' (see Figure 6-8).

6.4. Dreyer's *Scientific Papers*, further

observations and a modern revision

Another important step in revising the Herschel catalogues was made by John Louis Emil Dreyer (see Figure 6-14), a former student of Heinrich d'Arrest in Copenhagen. Already the *New General Catalogue* of 1888 contains 2488 Herschel objects, based on Dreyer's analysis of the three catalogues (Figure 6-13).

No.	G. C.	J. H.	W. H.	Other Observers.	Right Ascension, 1860·0.	Annual Precession, 1880.	North Polar Distance, 1860·0.	Annual Precession, 1880.	Summary Description.	Notes.
					h m s	s	° ′	″		
1	1	...	...	d'A	0 0 4	+3·07	63 4·3	−20·1	F, S, R, bet * 11 and * 14	
2	6246	...	...	Ld R*	0 0 6	3·07	63 6·0	20·1	vF, S, s of G.C. 1	
3	5080	...	...	m 1	0 0 6	3·07	82 28	20·1	F, vS, R, alm stell	
4	5081	...	...	m 2	0 0 16	3·07	82 23	20·1	eF	
5	...	...	...	St XII	0 0 37	3·08	55 25·0	20·1	vF, vS, N = * 13, 14	
6	...	...	...	Sw II	0 1 5	3·08	58 15·6	20·1	eF, vS, eE	
7	2	4014	...	...	0 1 14	3·07	120 41·2	20·1	eF, cL, mE, vgvlbM	
8	5082	...	...	O Struve	0 1 17	3·08	66 59	20·1	vF, N in n end	
9	5083	...	...	O Struve	0 1 27	3·08	67 0	20·1	F, R, * 9, 10 sf	
10	3	4015	...	...	0 1 28	3·06	124 38·9	20·1	F, cL, vlE, glbM	
11	...	...	...	St XII	0 1 29	3·08	53 19·9	20·1	vF, vS, vlE, 2 vF st inv	
12	4	1	III 868	...	0 1 34	3·07	86 10·2	20·1	eF, pL, vglbM	
13	5	2	III 866	...	0 1 35	3·08	57 20·8	20·1	vF, vS, S st + neb	
14	7	3	II 591	...	0 1 37	3·08	74 57·9	20·1	vF, pS, R, glbM	

Figure 6-13: Start page of Dreyer's *New General Catalogue*, published in 1888. The first entry, credited to William Herschel, is the 13.1 mag galaxy NGC 12 (III 868) in Pisces, discovered on 6 December 1790 (sweep 984).

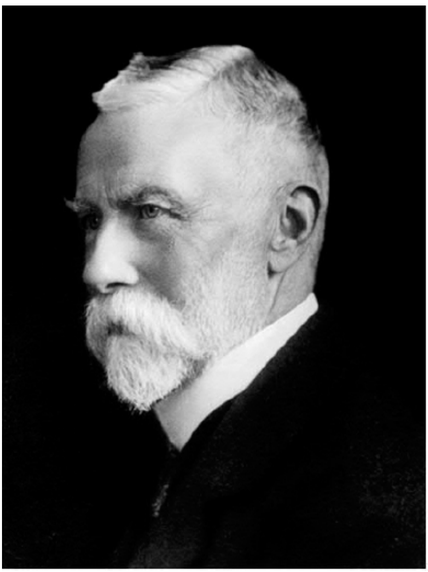
An even more detailed study of Herschel's objects was made for the *Scientific Papers of Sir William Herschel*, edited by Dreyer and published in 1912 (Figure 6-14).[1111] The monumental work fills two large-format volumes with altogether 1441 pages. What was the reason, why the collected papers did not appear until ninety years after his death in 1822? Of course, there were earlier plans, mainly advanced by John. But, despite the scientific reputation of his great successor, the matter remained unsuccessful. The main reason was, as so often, the money.

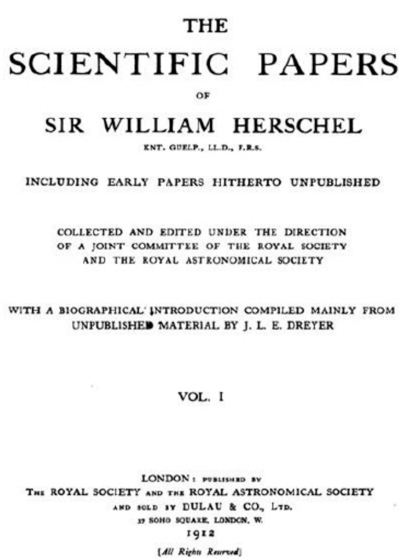
No serious publisher was found to undertake the risk of such an extensive work.[1112] Eventually, early in the year 1910, a joint committee of the *Royal Society* and the *Royal Astronomical Society* was appointed to put things forward. Of course, Dreyer was a member. The project was supported by William Herschel's grandson

Col. John Herschel, who left letters and papers from the estate to the committee.

It became the task of the 58-year-old Armagh Observatory Director to edit the bulky matter. The reason was simple: he was familiar with Herschel's methods and the results. Dreyer had spent four years at Birr Castle and observed many nebulae with Lord Rosse's 72-inch reflector. Soon after he published the NGC under the authority of the RAS.[1113] Moreover, he was an expert in the history of astronomy and had a profound knowledge of scientific literature. Due to this background the committee had no doubt that he was the right man for the job.[1114]

Dreyer was faced with a large number of papers (mainly from the *Philosophical Transactions*), among them the catalogues of nebulae, clusters and double stars, the discovery of Uranus (plus two moons), the sixth and seventh satellites of Saturn, the 'construction of the heavens' and reports about the construction of large telescopes.





THE

SCIENTIFIC PAPERS

OF

SIR WILLIAM HERSCHEL

KNT. GUELP., LL.D., F.R.S.

INCLUDING EARLY PAPERS HITHERTO UNPUBLISHED

COLLECTED AND EDITED UNDER THE DIRECTION
OF A JOINT COMMITTEE OF THE ROYAL SOCIETY
AND THE ROYAL ASTRONOMICAL SOCIETY

WITH A BIOGRAPHICAL INTRODUCTION COMPILED MAINLY FROM
UNPUBLISHED MATERIAL BY J. L. E. DREYER

VOL. I

LONDON: PUBLISHED BY
THE ROYAL SOCIETY AND THE ROYAL ASTRONOMICAL SOCIETY
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1912
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Figure 6-14: John Louis Emil Dreyer, Director of Armagh Observatory and editor of the monumental *Scientific Papers of Sir William Herschel*, published by the *Royal Society* in 1912.

First class. Bright nebulæ.

I.	1783	Stars.		M. S.		D. M.	Ob.	Description.	N.G.C.
1	Dec. 19	82 (δ) Ceti	f	2 17	n	0 8	7	cB. cL. iF. bM.	1055
2	—	3 Leonis	p	18 7	s	1 12	5	cB. cL. vgbM. N. R.	2775
3	—	34 Sextant	p	28 55	s	0 13	4	cB. pL. C. mbM.	3166
4	—	– –	p	28 27	s	0 10	4	cB. pL. C. mbM.	3169
5	30	81 Leonis	p	2 42	n	0 7	2	B. pS. iR. bM. r.	3655
	1784								
6	Jan. 19	64 Virginis	f	33 56	s	0 1	3	vB. pL. gmbM.	5363
7	23	49 Leonis	f	126 45	s	0 40	1	vB. L. R. The place inac.	4472*
8	—	32 (2d) Virg	f	2 50	n	0 48	5	cB. pL. iR. mbM. r.	4698
9	24	10 (r) Virg	f	3 12	s	0 35	4	cB. E. np sf. N and 2 bran. 3′ l.	4179
10	—	– –	f	33 37	n	0 4	4	vB. pL. lE. gmbM. 2′ l. 1¼′ b.	4643
11	Feb. 15	5 Comæ Be.	p	1 30	s	2 11	1	B. pL. lE. bM. m.	4153
12	19	6 Comæ	f	9 12	s	0 9	2	B. pS. R. BM. r.	4377
13	22	69 Leonis	p	7 57	n	0 2	3	vB. mE. mer. smbM. 7 or 8′ l. Fig. 11. Note.	3521

Figure 6-15: Start of the table for class I objects of Dreyer's revised version of Herschel's first catalogue in the *Scientific Papers* (note the new column N.G.C.)

Another focus was on unpublished material. Dreyer combed through the London archives of both Societies and examined the manuscripts of William, Caroline and John. A major source were the observing journals. With the original documents, he was – compared to Auwers or d'Arrest – in a privileged situation. His careful examination led to a major revision of the Herschel catalogues, enhanced by valuable comments. The catalogues in Dreyer's edition differ from the original published in the *Philosophical Transactions* (and in some cases even from the NGC). Moreover, he contributed what was in effect a scientific biography of Herschel, covering the first 56 pages of Volume I. It is followed by the section 'Unpublished Papers'. In the appendix of the Volume II, we find Herschel's observations of Messier objects. When the enormous task was finished in less than two years, Dreyer transferred the material to the committee, who initiated the layout and print. The preface is dated February 1912.

Guillaume Bigourdan made visual observation of 6380 NGC objects (!) with the 12.5-inch refractor at Paris Observatory. Of course, most of them are from the Herschel catalogues. So we have an independent confirmation for many objects and, moreover, newly determined positions (for 1900). During this huge task, many new nebulae were found. The result appeared 1919 in five volumes.1115

Of course, Dreyer was a great admirer of Bigourdan, already cataloguing 76 objects in the *New General Catalogue* and 322 in the *Index Catalogue*. Many were found to be mere stars, perhaps a result of the poor observing conditions in Paris around the turn of the century.

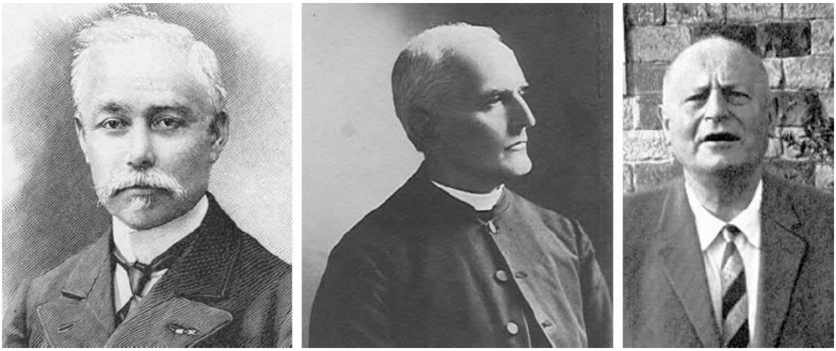
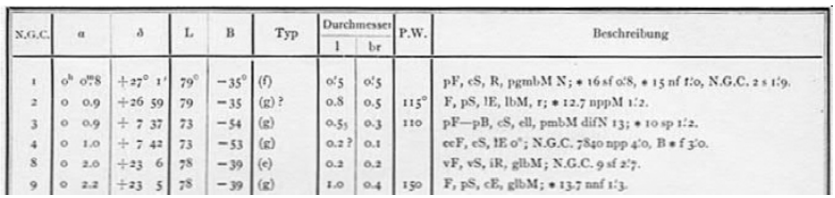


Figure 6-16: Observers of Herschel objects: Guillaume Bigourdan, Johann Georg Hagen and Karl Reinmuth.



N.G.C.	α	δ	L	B	Typ	Durchmesser l	Durchmesser br	P.W.	Beschreibung
1	0ʰ 0ᵐ.8	+27° 1′	79°	−35°	(f)	0′.5	0′.5		pF, cS, R, pgmbM N; ✱ 16 sf 0′.8, ✱ 15 nf 1′.0, N.G.C. 2 s 1′.9.
2	0 0.9	+26 59	79	−35	(g)?	0.8	0.5	115°	F, pS, lE, lbM, r; ✱ 12.7 nppM 1′.2.
3	0 0.9	+ 7 37	73	−54	(g)	0.55	0.3	110	pF—pB, cS, ell, pmbM difN 13; ✱ 10 sp 1′.2.
4	0 1.0	+ 7 42	73	−53	(g)	0.2?	0.1		eeF, eS, lE 0°; N.G.C. 7840 npp 4′.0, B ✱ f 3′.0.
8	0 2.0	+23 6	78	−39	(e)	0.2	0.2		vF, vS, iR, glbM; N.G.C. 9 sf 2′.7.
9	0 2.2	+23 5	78	−39	(g)	1.0	0.4	150	F, pS, cE, glbM; ✱ 13.7 nnf 1′.3.

Figure 6-17: First entries in Reinmuth’s catalogue *Die Herschel-Nebel* of 1926.

Even after Bigourdan and despite the dominance of photography, systematic visual observations of NGC objects (and thus that of Herschel) continued. The last representative was Johann Georg Hagen, Director of Vatican Observatory, known from the story of Herschel’s ‘hole in Scorpius’. He planned the observation of a large fraction of NGC objects with the fine 16-inch Zeiss refractor at Castelgandolfo to develop a numerical visual brightness scale for non-stellar objects, similar to that for stars. The study should have also led to a revision of the NGC by creating a uniform database. Hagen started in 1911 and observed about 5800 objects! The result was published 1922 as *A preparatory catalogue for a Durchmusterung of nebulae. The zone catalogue*.1116

In 1919, Karl Reinmuth of Königstuhl Observatory (Heidelberg), started a photographic study of all objects north of -20° declination, listed in John Herschel's *General Catalogue* and Dreyer's 'GC supplement'.1117 The work was initiated Max Wolf. Plates were taken with the 40 cm Bruce refractor. The catalogue, titled *Die Herschel-Nebel*, appeared in 1926.1118 It contains 4445 objects, sorted by right ascension (for 1875). The table gives: NGC-number, NGC-position, galactic longitude/latitude, type (Wolf's classification), size, position angle and description (based on the Herschel scheme). Reinmuth's work brought great progress, due to its homogeneity and completeness.

In 2008, the author presented a revised version of the Herschel catalogues. The dataset, available in the Internet, is continuously updated.1119 Table 6-12 shows published catalogues and revisions, containing a larger number of Herschel objects. In some cases (Lord Rosse, d'Arrest etc.), objects were selected for observation. Table 6-13 gives the 19th and early 20th century designations for Herschel objects.

Publication	Author	Year	Obj	Remarks
three Herschel catalogues (original)	**W. Herschel**	1786–1802	C	observations
three Herschel catalogues	Bode	1788–1804	C	German version
Zone Catalogue (unpublished)	C. Herschel	1825	CR	created for J. Herschel
Slough Catalogue	**J. Herschel**	1833	SR	Slough observations
Cape Catalogue	**J. Herschel**	1847	S	Cape observations
William Herschels sämtliche Schriften	Pfaff	1850	SR	German; 1st catalogue
Herschels Verzeichnisse von Nebelflecken und Sternhaufen	Auwers	1862	CR	German version
Siderum Nebulosorum Observationes Havnienses	**D'Arrest**	1867	S	Copenhagen observations (in Latin)
General Catalogue (GC)	J. Herschel	1864	AC	first whole sky catalogue ('database')
On the Construction of Specula of Six-feet Aperture	**Lord Rosse**	1861	S	Birr Castle observations
Observations of Nebulae and Clusters of Stars	**Dreyer**	1880	S	Birr Castle observations
New General Catalogue / Index Catalogue (NGC/IC)	Dreyer	1888–1908	AC	second whole sky catalogue
Scientific Papers of Sir William Herschel	Dreyer	1912	CR	extension
Observations des nébuleuses et d'amas stellaires	**Bigourdan**	1919	AC	Paris observations
zone catalogue (different from CH)	**Hagen**	1922	AC	Vatican observations
Die Herschel-Nebel	**Reinmuth**	1926	CR	photographic revision, includes GC
Historic Herschel Catalogues (Internet)	Steinicke	since 2008	CR	modern revision

Table 6-12: Published catalogues and revisions concerning Herschel objects; bold = based on observations. Objects (Obj): C = complete, CR = complete revision, SR = selected revision, AC = almost complete, S = selection (for observations).

Astronomer	Designation	Astronomer	Designation
William & John Herschel	VIII. 61	Auwers	VIII. 61
Lord Rosse	VIII. 61	Winnecke	H. VIII, 61
Wollaston	Hers. VIII. 61	Tempel	VIII 61
Bode	VIII, 61	O. Struve	H. VIII. 61
Smyth	61 H. VIII.	Dreyer	VIII. 61, VIII 61
Webb	H. VIII 61	Bigourdan	VIII 61
d'Arrest	H. VIII. 61	Reinmuth	VIII. 61

Table 6-13: In the classical literature, we find different forms of Herschel's class designation (sorted by date).1120

1049 Herschel Mrs. J. (1876: 181). John Herschel worked as secretary for the *Royal Society*. In 1827 he was elected President of the *Astronomical Society of London*, founded in 1820.

1050 Herschel Mrs. J. (1876: 183).

1051 RAS W.2/3.1–8 and RAS C.2/3.2. Obviously, Caroline had parted with other documents too, like the 'Register of Gages' and the 'Register of Sweeps', but she still kept William's papers from the *Philosophical Transactions* (bound in five volumes), Wollaston's star catalogue and Bode's *Uranographia*; see Herschel Mrs. J. (1876: 186–187).

1052 Lubbock (1933: 368). At that time, John had already made 13 sweeps (see Table 6-5).

1053 RS MS/279, Dreyer (1912a: lxiii-lxiv).

1054 William used the English form 'Caroline', like he did for himself (omitting Wilhelm). His brother Dietrich was often called 'John', due to his other first name Johann.

1055 Herschel Mrs. J. (1876: 196).

1056 When writing about Bode's contribution, Caroline curiously does not mention his German version of the third Herschel catalogue, published in 1804 in the *Berliner Jahrbuch*.

1057 Dreyer (1912a: lxiv).

1058 Herschel Mrs. J. (1876: 146). David Brewster (1781–1868), British physicist.

1059 Herschel Mrs. J. (1876: 195). Carl Friedrich Gauss (1777–1855), German mathematician and astronomer.

1060 President John Herschel transferred the duty to his friend South; see South (1830), Herschel Mrs. J. (1876: 222). Alas, the laudator did not mention Caroline's 3rd and 4th comet (both found 1790). On 13 February 1835, she was elected an honorary member of the *Royal Astronomical Society* (women fellows were still not allowed). Three years later, the *Royal Irish Academy*, Dublin, elected her an honorary member; Herschel Mrs. J. (1876: 300).

1061 Hoskin (2013: 203).

1062 For John Herschel's life and work see Clerke (1895); Evans (1969), Buttman (1970), Millmann (1980: part II), Ring (1992), Warner (1992), Chapman (1993), Case (2015). The *Royal Society* celebrated John's 200th birthday in King-Hele (1992).

1063 RAS W.2/6: 25, Hoskin (2012b).

1064 RAS J.1/1.

1065 In a letter to John in London, written on 14 February 1821, William gave some hints about double stars. In March, he sent Flamsteed's *British Catalogue* and the *Atlas Coelestis* to his son; Lubbock (1933: 357).

1066 Herschel J., South J. (1824). According to Buttmann (1970: 32) the 5-ft was made by Dolland; further a 5-in / 7-ft refractor is mentioned. The publication with South was not John's first astronomical paper; one had appeared already in 1819 in volume 1 of the *Edinburgh Philosophical Journal*: 'Sir William Herschel's Researches Respecting the Distances of the Fixed Stars'; Herschel J. (1819). It contains a drawing of the Tully refractor; King (1949).

1067 See also Hoskin (1987: Fig. 3); Warner (1979). South and Herschel later used an 11¾-in refractor.

1068 RAS J.1/5.1–4.

1069 Herschel Mrs. J. (1876: 193).

1070 Steinicke (2010a: chapter 3).

1071 The acknowledgment reads: "Received July 1, – Read November 21, 1833". John Herschel became a Fellow of the *Royal Society* (FRS) in 1813.

1072 Herschel J. (1835), Ashbrook (1984: 37-41), Steinicke (2010a: chapter 5), Evans (1969). At the Cape, Herschel made even better mirrors than his father's. Sometimes the aperture was reduced to 12". An example is his observation of the Trapezium in M 42 (Herschel J. 1847: 30). It should be mentioned that John found a 6th star (11.2 mag) on 13 February 1830, while observing at Slough with South's 11¾-in refractor (F in Figure 3-31).

1073 He catalogued 629 non-stellar objects; see Dunlop (1828), Cozens (2008), Steinicke (2010a: chapter 4.4).

1074 Feldhausen is one mile east of the Table Mountain. There is a monument, erected in 1841 at the former place of the reflector, the Herschel Memorial Obelisk (now the Grove Primary School, Feldhausen Road, Claremont, Cape Town).

1075 Herschel J. (1847).

1076 John inspected Leo on 18 March 1836, observing 13 objects, five were new (four galaxies, one star). The altitude was $+40°$. All other 'northern' objects are below -2° declination, the effective upper limit of the Cape observations.

1077 See also: Nasim (2014).

1078 Herschel J. (1864).

1079 Buttmann (1970: 158).

1080 Steinicke (2010a: chapter 7).
1081 Dreyer (1878, 1888).
1082 Steinicke (2014c).
1083 Parsons W. (1861). The objects are sorted by h-number: Lord Rosse curiously wrote ‘H’; see Steinicke (2014c).
1084 Parsons L. (1880).
1085 Smyth (1844); see also Steinicke (2010a: chapter 6.5).
1086 Webb (1859). Thomas Webb (1807–1885) was a British clergymen and amateur astronomer. His ‘common telescope’ was a 3.7-inch Tully refractor; see Steinicke (2010a: chapter 9.9).
1087 Pfaff (1850). This is the second edition of his book; it presents the first Herschel catalogue in an appendix. The first edition appeared in 1826. Wilhelm Pfaff (1774–1835) was a German mathematician and astronomer.
1088 Auwers (1862: 3).
1089 d’Arrest (1856: 360). Further volumes, already planned by Pfaff, failed to appear.
1090 Auwers (1862); see also Steinicke (2010a: chapter 6.19).
1091 Winnecke (1863).
1092 Auwers (1862: 3).
1093 The observatory owned a 10-ft reflector, made by Herschel and personally installed in the summer of 1786.
1094 Baily (1845).
1095 Auwers (1862: 4).
1096 d’Arrest (1856).
1097 Auwers (1862a: 3).
1098 Auwers (1862a: preface). Eduard Luther (1816–1887), German astronomer and Director of Königsberg Observatory.
1099 Auwers (1865: 7).
1100 Herschel W. (1811).
1101 See Cozens (2008) for Lacaille’s southern observations.
1102 Already John had trouble with M 103: in the *Slough Catalogue* the star cluster (h 126) is only identified with Wilhelm Struve’s double star Σ 131.
1103 Steinicke (2010a: 183). The two are: NGC 4989 (II 185), found by William on 24 April 1784, and NGC 504 (h 107), found by John on 22 November 1827.
1104 Auwers (1862a: 4).
1105 Auwers (1865: 5). Actually, there are 803 objects, not re-observed by John.
1106 A third treatment is due to d’Arrest, who claimed an even better accuracy for Herschel than Auwers. His result is due to the object sample, observed by him; d’Arrest (1867).
1107 Anon (1863).
1108 d’Arrest (1862).

1109 d'Arrest (1861).
1110 d'Arrest (1867); Steinicke (2010a: chapter 8.6)
1111 Steinicke (2012e).
1112 The same is true for this book, self-published by the author.
1113 Dreyer (1878, 1888).
1114 Steinicke (2010a: chapter 8.1).
1115 See Steinicke (2010a: chapter 9.22).
1116 Hagen (1922); Becker (1928). Hagen's 'zone catalogue' should not be confused with Caroline's *Zone Catalogue*.
1117 Karl Reinmuth (1892–1979), German astronomer.
1118 Reinmuth (1926).
1119 See: www.klima-luft.de/steinicke. The site also contains revised versions of the *Messier Catalogue*, *Slough Catalogue*, *Cape Catalogue*, *General Catalogue*, Auwers' list of new nebulae, Dreyer's GC supplement and, of course, the NGC/IC.
1120 VIII 61 = NGC 1778 (OC, Aur). In the modern literature there is also confusion; a recent example is O'Meara (2007). Otto v. Struve (1819–1905), Baltic-german astronomer and Director of Pulkovo Observatory; son of Wilhelm v. Struve.

Epilogue

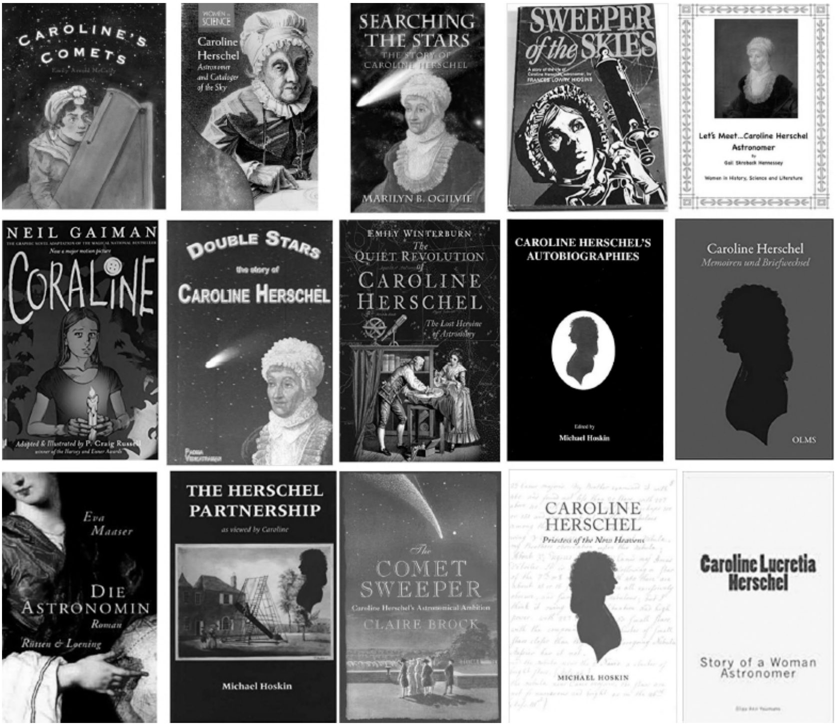
Concerning William Herschel's main astronomical discoveries, we have a ranking, compiled by his son John. It is titled 'List of the most important of Sir William Herschel's discoveries which have since been verified; drawn up by John Herschel in May 1825".[1121] He added comments about their confirmation. Interestingly the Sun's motion towards λ Her ('solar apex') is not mentioned. From a modern point of view, most of John Herschel's subjects refer to real astronomical phenomena, but other are not of value today. Here is the ranking in his actual words:

1. Discovery of a new Primary Planet and *two* of its satellites [Uranus, Oberon, Titania] revolving in planes nearly perpendicular to the plane of its own orbit.
2. The discovery of nearly 1000 double stars, and the *very important fact* that many of these pairs of stars form *binary systems* connected by mutual attraction; – confirmed by observations of South and myself.
3. The discovery of between 2000 and 3000 nebulae and clusters of Stars, and of the remarkable circumstance of the disposal of the vast number of the former in *strata* or irregularly extended beds in the heavens; – confirmed by my own observations.
4. The complete resolution of every part of the Milky Way into stars of various sizes.
5. The discovery of the gaseous nature of the Sun's luminous surface; – confirmed.
6. The discovery of two satellites of Saturn [Mimas, Enceladus]. N.B. It is not probable that they will ever again be seen in a Refracting telescope of less than 2 feet aperture, or in a Reflector of less than 4 feet.
7. The discovery of the period of the rotation of the ring of Saturn; – confirmed by Laplace.
8. Discovery of the independent of the heating and illuminating power of the solar rays [thermal radiation]; – confirmed.
9. Discovery of the coincidence in the times of the rotation on their axes of certain of the satellites of Jupiter and Saturn

with (the time of revolution round) their primaries and the extension of the analogy of our moon to all secondaries.

10. Discovery of the true hights of the Lunar Mountains, much misconceived by former and contemporary astronomers.
11. Discovery of a peculiar class of sidereal objects called by him Planetary Nebulae; – confirmed by M. Plana and myself at Turin last summer.[1122]
12. Discovery of Double Stars with contrasted colours and of many extraordinary facts regarding the colours of single stars; – confirmed.
13. Discovery of large tracts of loose nebulosity in the heavens unconnected with stars and not collected in patches of a sensible form [extensive diffused nebulosity].
14. Discovery of extra-ordinary occasional irregularities in the distribution of the belts on the disc of Jupiter.
15. Distinction between space-penetrating [power] &c. &c. telescopes.
16. Discovery of the variability of the star α Herculis.

A collection of books about William and Caroline Herschel, represented by their front covers.



The legacy of William and Caroline Herschel is very diverse and international. A general treatment of this subject is far beyond the scope of this book. Many institutions, both professionals and amateurs, deal with the work of the Herschels, though not always paying attention to the correct historical background.

Mention should be made of the *Royal Astronomical Society* and the *Royal Society*, the *Herschel Society* and the *Astronomical League*.[1123] The latter organization, based in the United States, offers two observing programs for amateur astronomers: the *Herschel 400*, offering the 'best' Herschel objects, visible in a moderate telescope, and the *Herschel 2500*, offering 'all' objects (whatever this means). For the latter, a larger telescope is needed. Anyone who has made the relevant list receives a nice certificate.

1121 Lubbock (1933: 289–290).
1122 Giovanni Plana (1781–1864), Italian astronomer and mathematician.
1123 For the websites see the Internet sources following the References.

Appendix

Visitors

This section is the result of a study about the visitors to the Herschels at their various locations (Bath, Datchet, Clay Hall, Slough). With a thorough examination, it is possible to identify most of the people mentioned in the various documents written by Caroline. The information relates to a period from 1777 to 1818 and is based on all available sources (see table). The resulting dataset has 651 entries; 423 different persons were identified. The statistics are shown in the next table. Of course, there are errors in the literature, for example regarding 'visitors' who were too young or old (or even dead) to meet the Herschels.

The first (documented) guest was the Astronomer Royal Nevil Maskelyne in 1777 (Bath). The last was the Austrian nobleman Maximilian Joseph von Österreich-Este on 14 October 1818 (Slough).

Source	Author	Location	Period	Entries
Visitor Book	Caroline	Herschel Museum, Bath	1783–1792	477
Temporary Index (visitor list)	Caroline	RAS C. 3/1.1–2	1780–1808	95
Memoir	Mrs. John Herschel	Herschel Mrs. J. (1786)	1786–1818	55
Autobiography	Caroline	Hoskin (2003)	1777–1787	29
Observing records	Caroline	Journals, Fixt Stars, Sweeps, Reviews	1782–1813	26
William and Caroline Herschel	Hoskin	Hoskin (2014a)	1786–1794	14
Memorandum	William	RAS W. 7/8	1779	1

Sources of the visitor dataset.

Category	Number
identified persons	301
unidentified persons	115
unnamed entries	57
astronomers	23
physicists	5
other Scientists	31
Fellows of the *Royal Society*	42
noblemen/women	129
visitors at Bath	12

visitors at Datchet	19
visitors at Clay Hall	21
visitors at Slough	364

Visitor statistics (for the four places only identified persons are counted).

81% visitors were male, 19% female. There are 19 different nationalities: 49% are British (without Scots), 13% German, 8% French, 7% Scottish, 5% Italian, 5% Irish, 3% Dutch, 2% Swiss, 2% Austrian; the rest are Russian, Polish, Danish, Hungarian, Swedish, Spanish, Portuguese, Luxembourgish, Lithuanian, and American. The American was Chief Bowles, Leader of the Cherokee Nation, visiting Slough in 1791. The Lithuanian was Joachim Chreptowicz, Chancellor of Lithuania, writer and poet (Slough, 1788). The Luxembourger was the astronomer Peter Ungeschick (see next table). He died in London only 3½ months after his visit to Slough on 8 August 1790.

All noble men and women (with one exception) visited the Herschels when they lived in the Windsor area, starting with George III on 30 August 1782 at Datchet. By 17 August 1787 (Slough), the King had come seven times. On the final visit he was accompanied by Queen Charlotte (see figure). The exception was the British antiquarian and science author Henry Charles Englefield, 7th Baronet, who probably visited the Herschels in Bath in 1778.

Royal guests: King George III and Queen Sophie Charlotte.

The most frequent visitors were:

- William Watson Jr	11-times	1779–1817	Bath, Clay Hall, Slough
- James Lind	10-times	1783–1807	Datchet, Slough
- Charles Blagden	9-times	1783–1791	Datchet, Clay Hall, Slough

Of course, astronomers are interesting; 24 visited the Herschels at various places (see following Table). The most frequent visitors were Nevil Maskelyne and Patrick Wilson (seven visits each). Maskelyne was also the first astronomer (1777 at Bath), Wilson the last (1805 at Slough).

The youngest visitors were two sons of George III; both came to the Herschels in 1783–84 (Datchet). Prince Adolphus Frederick, Duke

of Cambridge (1774–1850) was 9–10 years old and Prince Augustus Frederick, Duke of Sussex (1773–1843) was 10–11 years old. The oldest people were 76 (visiting Slough): the English physician William Heberden (1710–1801) on 26 October 1786 and the German noblewoman Anne Liddell (1712–1794), Baroness Ravensworth, on 14 June 1788.

There are other interesting people among the scientists, like the English physicist Henry Cavendish, the Scottish mathematician John Playfair, the English botanist Joseph Banks (President of the *Royal Society*), the Scottish engineer James Watt, and the French mathematician Adrien-Marie Legendre.

Amazingly, although Herschel was an eminent instrumentalist and composer, few musicians visited him. We have Christopher Papendiek, German court musician to George III (17 June 1787), Charles Burney, English music historian (August 1786)[1124], the German Organist Hossler (23 April 1791), Wilhelm Jakob Moritz Graf von Redern, Prussian General Director for Drama and Music (8 August 1791) and the English musician Joah Bates (13 September 1792). All of these came to Slough.

When the Austrian composer Joseph Haydn visited Slough on 15 June 1792, William was travelling in Scotland. He sadly missed him. Caroline attended to the illustrious guest and presented the collection of telescopes. That Haydn was inspired by the cosmic scenery for his oratorio ‘The Creation’ in 1797/98 is probably a legend.

Name	Position	Nationality	N	Years	Location
Nevil Maskelyne	5. Astronomer Royal, Greenwich Observatory	English	7	1777–1803	B, D, S
Alexander Aubert	amateur astronomer	English	6	1782–90	B, D, C, S
Anthony Shepherd	Plumian Professor at Cambridge	British	3	1782–86	B, S
Patrick Wilson	Professor of astronomy at Glasgow	Scottish	7	1783–1805	D, S
Hans Moritz v. Brühl	diplomat and astronomer	German	4	1785–91	C, S
Franz Xaver v. Zach	Director of Seeberg Observatory	German	1	1785	C
Thomas Hornsby	Savilian Professor at Oxford University	British	1	1785–86	C
Samuel Vince	Plumian Professor at Cambridge	English	4	1785–99	C, S
Barnaba Oriani	Director of Brera Observatory, Milan	Italian	2	1785–88	S
Jan Śniadecki	Director of Kraków Observatory	Polish	3	1785-87	S
William Lax	Lowndean Professor at Cambridge	English	1	1787	S
Giuseppe Piazzi	Director of Palermo Observatory	Italian	2	1787–88	S
Jean Dominique Cassini	Paris Observatory	French	1	1787	S
Pierre Méchain	astronomer and surveyor	French	1	1787	S
Robert Blair	Professor at Edinburgh	Scottish	1	1788	S
Antoine Darquier	Toulouse Observatory	French	1	1788	S
Joseph-Jerome de Lalande	Hôtel de Cluny Observatory	French	2	1788	S
Edward Pigott	variable star observer	English	1	1788	S
Salvador Jiménez Coronado	Director of the first Madrid Observatory	Spanish	2	1789	S
Alexis-Marie de Rochon	astronomer, physicist and maritime optician	French	1	1790	S
Peter Ungeschick	Director of Mannheim Observatory	Luxembourgish	1	1790	S
Stephen George Demainbray	Kew Gardens Observatory (King's astronomer)	British	1	1791	S
John Brinkley	1. Astronomer Royal for Ireland, RAS President	English	2	1791	S
Karl Felix v. Seyffer	Göttingen Observatory	German	1	1792	S

These 24 astronomers visited the Herschels; N = number of visits; Location: B = Bath, D = Datchet, C = Clay Hall, S = Slough.

Herschel’s journeys

The following table lists 39 journeys, made between 1781 and 1817

(it is perhaps incomplete). All destinations, except Paris, were located in England, Scotland and Wales. William Herschel was mainly accompanied by his family (Mary, John) and friends. Miss Baldwin is Sophia Baldwin, daughter of Mary's (Lady Herschel) brother Thomas. Miss White's identity is unknown (she could have lived in Newbury). Komarzewski is the Polish lieutenant-general and mineralogist Jean-Baptiste Komarzewski. Observations were made on some tours, mostly using the transportable 7-ft 'skeleton reflector'. Since 1809 there was an annual summer tour with the family.

Year	Dates	D	Main destinations	Fellow travellers	Observations	Src
1781	2–4 May	3	Greenwich, London (RS)		double stars	F1
1782	24 May – 6 June	14	Greenwich, Windsor		double stars	F3
1782	2–4 July	3	Windsor			F3
1786	3 July – 19 Aug.	48	Hanover	Alexander		Mem
1791	13–20 July	8	Leicester, Derby	Mary		T
1792	29 May – 15 July	48	Wales, Birmingham, Scotland, Devon, Thornhill	Komarzewski		T
1792	22 July – 9 Aug.	19	Southwest England, Birmingham	Komarzewski		T
1792	1–5 Oct.	5	Bath, Bristol, Newbury			T
1793	19 July – 6 Aug.	19	Oxford, Stratford, Birmingham, Derby, Thornhill	Mary, Miss S. White		T
1794	1–10 Sep.	10	South coast	Mary, Miss S. White		T
1795	1–16 Apr.	16	Bath	Mary		T
1795	26 Aug. – 18 Sep.	24	Oxford, Gloucester, Bath, Exeter	Mary, Miss S. White	stars	T
1796	30 July – 3 Sep.	36	Bath, Glastonbury, Exeter, Dorchester, Salisbury		stars	T
1797	1–24 Aug.	24	Dartford, Rochester, Canterbury, Dover			T
1798	30 July – 3 Sep.	36	Bath, Exeter, Salisbury	Mary, John, Miss Baldwin		T
1799	3–4 Mar.	2	Bath		stars	R5
1799	20–31 Aug.	12	Bath		neb. & clusters	R5
1799	17 Sep. – 18 Oct.	32	Bath		NGC 7009	R5
1800	4–18 Feb.	15	Bath		sun	R6
1800	31 July – 4 Sep.	36	Canterbury, Dover, Kensington	Mary, John, Miss Baldwin		T
1800	1–3 Dec.	3	Bath		sun	R6
1801	13–19 June	7	Bath		sun	R6
1801	29 July – 31 Aug.	34	Wales	Mary, John	sun	T
1802	13 July – 25 Aug.	44	Paris	Mary, John, Miss Baldwin		T
1805	15–27 Aug.	13	Portsmouth, Chichester, Brighton, London	Mary, John, Miss Baldwin		T
1806	1 Aug. – 8 Sep.	39	Wales	Mary, Miss Baldwin		T
1807	18–28 Aug.	11	Hastings, Eastbourne, Brighton, London			T
1807	29–4 Sep.	6	Brighton	Mary, John, Miss Baldwin		T
1808	7 Apr. – 9 May	33	Bath	Mary, John, Miss Baldwin		T
1808	4–11 Dec.	8	Brighton	Mary, John, Miss Baldwin		T
1809	12 July – 3 Sep.	54	Lakes, Yorkshire	Mary, John, Miss Baldwin		T
1810	12 July – 3 Sep.	54	Newcastle, Lakes, Glasgow, Edinburgh, Leeds	Mary, John, Miss Baldwin		T
1811	22 July – 18 Sep.	59	Leicester, Sheffield, Lakes, Edinburgh, Glasgow	Mary, John, Miss Baldwin	Great Comet	T
1812	4 Sep. – 2 Oct.	29	Devon	Mary, John, Miss Baldwin		T
1813	30 Aug. – 23 Sep.	25	Hastings, Eastbourne, Southampton	Mary, John, Miss Baldwin		T
1814	17 Aug. – 5 Sep.	20	Bath, Exeter			T
1815	12 Aug. – Sep.?		Bath, Dawlish, Exeter	John		T
1816	17–27 June	11	Cambridge,	Mary, Miss Baldwin		T
1817	12 Aug. – 20 Sep.	40	Bath, Dawlish, Exeter	Mary, John, Miss Baldwin		T

Herschel's 39 documented journeys were made between 1781 and 1817. D = number of days. Src = source: F = *Fixt Stars*, R = *Review*, Mem = *Memoir*, T = Herschel's travel diary (RAS W. 7/15). All tours started and ended from Slough, except that in 1781

and 1782, when living in Bath. Due to other documents, there might have been more, but neither dates nor destinations are given.

Timeline

The table gives key events, from the building of the first instruments to Caroline's *Gold Medal*, which she received in 1828. The sites (B = Bath, C = Clay Hall, S = Slough, H = Hanover) do not refer to the event but to the place where William and Caroline lived at the time. The most important observing campaigns are assigned as a reference in the column 'Obs' (R1–3 = three star reviews, Sw = sweeps). The entry 'Guest' concerns important visits mentioned in the text; they are mainly worth mentioning in connection with observations.

Year	Date	Site	Obs	Event
1773	Spring	B		First entry in 'Experiments' (work with refractors)
1773	10 May	B		Books of Smith and Ferguson purchased
1773	1 June	B		Small reflector built
1774	January	B		Reflector: 5.5-ft / 4-in
1774	1 March	B		First observation: Saturn, M 42; *Journal No. 1* opened
1774	3 March	B		First drawing of M 42
1774	9 April	B		θ Orionis seen as triple star, Mizar as double star
1774	26 April	B		First micrometer used
1774	August	B		*British Catalogue*, Harris's maps and an astronomical clock purchased
1774	13 November	B		First Moon observation
1774	15 December	B		First Jupiter observation
1775	7 March	B		*Fixt stars No. 1* opened
1775	8 September	B		Earthquake at Bath
1776	early	B		Reflector: 10-ft / 9-in
1776	1 May	B		Reflector: 7-ft / 4-in
1776	13 July	B		Reflector: 20-ft / 12-in ('small 20-ft')
1776	11 November	B		Trapezium in M 42 discovered (4th star)
1777	8 April	B		First Mars observation
1777	17 April	B		First Venus observation
1777	20 October	B		First observation of Mira
1778	28 January	B	R1	First star review (Sirius, Procyon)
1778	8 April	B	R1	Castor seen as double star
1778	15 November	B		William's 40th birthday
1778	November	B		Reflector: 7-ft / 6.2-in (standard telescope)
1779	19 April	B		First observation of the Sun
1779	17 August	B	R2	Second star review started; *Review No. 1* opened
1779	22 August	B	R2	M 13 observed
1779	24 August	B	R2	Polaris found to be a double star
1779	29 August	B	R2	Discovery of ε Lyr as 'double double'
1779	24 September	B	R2	New micrometer used
1779	5 December	B	R2	Discovery of first non-stellar object (NGC 2232)
1780	11 May	B	R2	Paper read: observations of Mira
1780	6 August	B	R2	M 31 observed
1780	28 August	B	R2	Guest: William Watson (Jupiter, small 20-ft)
1780	8 September	B	R2	Guest: William Watson (Moon)
1780	26 September	B	R2	New primary and secondary mirrors for the 7-ft
1781	January	B	R2	Plan for a 30-ft reflector with 36-in mirror
1781	13 March	B	R2	Discovery of Uranus
1781	3 May	B	R3	*Royal Society* in London visited

Year	Date	Site	Obs	Event
1781	11 August	B	R4	36-in mirror casted
1781	26 April	B	R2	Paper read: discovery of Uranus
1781	2 May	B	R2	Visit at Greenwich
1781	20 July	B	R2	Guest: Patrick Brydone
1781	20 October	B	R2	Second star review ends
1781	October	B	R3	*Atlas Coelestis* received
1781	22 October	B	R3	Third star review started
1781	15 November	B	R3	*Royal Society* letter (on 43rd birthday): William receives *Copley Medal* for Uranus
1781	6 December	B	R3	*Copley Medal* handed over in London; William elected Fellow of the *Royal Society*
1781	6 December	B	R3	Paper read: parallax of stars
1781	December	B	R3	Mayer's double star catalogue and Messier's second catalogue received
1782	10 January	B	R3	Paper read: first catalogue of double stars
1782	20 May	B	R3	Visit to Greenwich
1782	1 June	B	R3	Visit to Greenwich (with Caroline)
1782	2 June	B	R3	Guest: Alexander Aubert
1782	15 June	B	R3	Guest: Maskelyne, Shepherd, Playfair, Aubert, Arnold
1782	July	B	R3	Name 'Georgium Sidus' proposed by Herschel for Uranus
1782	2 August	D	R3	Move to Datchet
1782	28 August	D	R3	Caroline's *Book of Observations* opened; first observations
1782	30 August	D	R3	Guest: George III (M 31, M 11)
1782	3 September	D	R3	Guest: George III (double stars)
1782	7 September	D	R3	Discovery of planetary nebula NGC 7009 in Aquarius
1782	27 September	D	R3	Discovery of Herschel's Garnet Star (μ Cep)
1782	30 September	D	R3	Caroline observed M 27 (not identified)
1782	1 December	D	R3	Guest: George III (Uranus, 10-ft); small 20-ft shown
1783	1 January	D	R3	Guest: James Lind
1783	26 February	D	R3	Caroline discovered her first object: NGC 2360
1783	6 March	D	R3	Paper read: first on motion of the Sun (towards λ Her)
1783	28 April	D	R3	Guest: George III (Uranus, M 35)
1783	30 April	D	R3	Guest: Joseph Banks (Uranus)
1783	3 May	D	R3	Lowest elevation with 7-ft: 2° for M 7
1783	May	D	R3	Messier's final catalogue received
1783	31 June	D	R3	Guest: Prince William (Jupiter, Saturn)
1783	4 July	D	R3	Guest: Mr. Hawkings (Polaris)
1783	8 July	D	R3	Caroline used small sweeper
1783	17 July	D	R3	Guest: Prince William
1783	23 September	D	R3	Caroline discovered galaxy NGC 253 in Sculptor
1783	26 September	D	R3	Third star review ended
1783	27 September	D		Guest: Patrick Wilson (2 days)
1783	29 September	D		Guest: Alexander Aubert, Charles Blagden
1783	28 October	D		Reflector: 20-ft / 18.7-in ('large 20-ft'); trial sweep
1783	29 October	D	Sw	Sweep campaign started with 20-ft (horizontal sweeps); first 'vacant fields' seen
1783	30 October	D	Sw	First object found in a sweep: NGC 7507 (sweep 7)
1783	14 November	D	Sw	First Mercury observation (naked eye)
1783	19 November	D	Sw	Bar mechanism installed (sweep 26)
1783	20 November	D	Sw	Front-view test of 20-ft (sweep 29)
1783	29 November	D	Sw	Guest: Edward Nairne, Mr. Collins (Great Comet of 1783)

Year	Date	Site	Obs	Event
1783	13 December	D	Sw	First vertical sweep (42)
1783	18 December	D	Sw	Caroline opens document *Sweeps No. 1* (sweep 46); James Lind was present
1783	19 December	D	Sw	First 'star gage' (sweep 55)
1783	23 December	D	Sw	*Review No. 4* closed
1783	24 December	D	Sw	Sidereal time used (sweep 62)
1783	30 December	D	Sw	PD index installed (sweep 68)
1783	31 December	D	Sw	Caroline injured by iron hook of 20-ft; fortunately, Dr James Lind was present
1784	1 January	D	Sw	Caroline's first zone catalogue of Flamsteed stars
1784	16 January	D	Sw	Observing chair installed (sweep 76)
1784	23 January	D	Sw	M 49 problem (sweep 105–111)
1784	24 January	D	Sw	PD string installed (sweep 112)
1784	30 January	D	Sw	Bell mechanism installed (sweep 134)
1784	11 March	D	Sw	M 105 trio discovered (sweep 164)
1784	14 March	D	Sw	Guest: Alexander Gordon, James Lind
1784	17 March	D	Sw	Wind damaged the 20-ft
1784	21 March	D	Sw	William's faintest object discovered: NGC 2843 (15.5 mag); sweep 208
1784	23 April	D	Sw	Guest: Charles Blagden ('stratum of Coma Berenices')
1784	24 April	D	Sw	Discovery of object no. 1000 (sweep 402)
1784	19 May	D	Sw	Guest: James Lind (M 3)
1784	21 May	D	Sw	Discovery of 'hole in Scorpius' (sweep 222)
1784	17 June	D	Sw	Paper read: first on the construction of the heavens
1784	24 June	D	Sw	Quadrant installed (sweep 232)
1784	12 July	D	Sw	*Fixt stars No. 7* closed
1784	19 July	D	Sw	Guest: Henry Temple, James Lind
1784	21 July	D	Sw	End of *Fixt Stars* series (sweep 236)
1784	7 August	D	Sw	Smallest object found: NGC 6629 (16"); sweep 245
1784	15 August	D	Sw	Guest: Barthélemy Faujas de Saint-Font
1784	6 September	D	Sw	Discovery of the Veil Nebula in Cygnus (sweep 258)
1784	5 October	D	Sw	Start of eastern sweeps (sweep 281)
1784	November	D	Sw	William's autobiographical manuscript sent to the European Magazine
1784	9 December	D	Sw	Paper read: second catalogue of double stars
1784	21 December	D	Sw	End of *Journal No. 10A* (sweep 350)
1785	1 January	D	Sw	William's longest night (12.8 h)
1785	6 January	D	Sw	Equinox of date (1785) applied (sweep 351)
1785	6 January	D	Sw	Guest: Jean Hyacinthe de Magellan
1785	3 February	D	Sw	Paper read: second on the constructions of the heavens
1785	16 March	D	Sw	First sweep in the north, above the pole (sweep 289)
1785	11 April	D	Sw	William's monster sweep 396; Coma Cluster objects found
1785	27 April	D	Sw	Bar index installed (sweep 403)
1785	6 May	D	Sw	Guest: Moritz v. Brühl, Alexander Aubert, Franz Xaver v. Zach
1785	10 June	C	Sw	Move to Clay Hall (Old Windsor)
1785	24 September	C	Sw	PD clock installed (sweep 440)
1785	September	C	Sw	George III grants £2000 for 40-ft
1785	1 October	C	Sw	Guest: Charles Blagden
1785	24 October	C	Sw	First catalogue of nebulae and clusters finished
1785	31 October	C	Sw	Mirror of 40-ft casted in London
1785	1 November	C	Sw	Guest: John Smeaton (sweeping)

Year	Date	Site	Obs	Event
1786	15 February	C	Sw	First sweep in the north, under the pole (sweep 523)
1786	10 March	C	Sw	Bar mechanism upgraded (sweep 538)
1786	3 April	S	Sw	Move to Slough
1786	22 April	S	Sw	Guest: Charles Blagden, Joseph Banks, Henry Cavendish
1786	27 April	S	Sw	Paper read: first catalogue of nebulae and star clusters
1786	4 May	S	Sw	William watched his first Mercury transit
1786	3 June	S	Sw	Guest: John Arnold, Richard Howard
1786	3 July	S	Sw	William's trip to Hanover and Göttingen with Alexander (1 month)
1786	20 July	S	Sw	Guest (of Caroline): Prince Charles, Ernest II, George Montagu
1786	23 July	S	Sw	Caroline's second zone catalogue of Flamsteed stars
1786	Summer	S	Sw	Construction of the 40-ft reflector in the garden
1786	1 August	S	Sw	Caroline's 1st comet
1786	August	S	Sw	Guest: Fanny Burney
1786	September	S	Sw	Guest: Marie Sophie Guntermann
1786	13 October	S	Sw	Front-view permanently used on 20-ft (sweep 609)
1786	18 October	S	Sw	Veil Nebula in Cygnus (NGC 6960) seen with the front-view (sweep 615)
1786	24 October	S	Sw	North America Nebula NGC 7000 discovered (sweep 620)
1786	25 October	S	Sw	Guest: Charles Blagden (front-view)
1786	26 October	S	Sw	Guest: William Heberden, Francis Wollaston
1786	28 November	S	Sw	M 42 seen with the 20-ft in the front-view mode
1786	11 December	S	Sw	Reference stars with PD < 45° used (sweep 645)
1787	11 January	S	Sw	Discovery of Oberon and Titania with 20-ft
1787	15 February	S	Sw	Paper read: moons of Uranus
1787	17 February	S	Sw	Reflector: 40-ft / 48-in saw first light (M 42)
1787	19 February	S	Sw	Guest: Charles Blagden (Uranus moons)
1787	17 March	S	Sw	Eyepiece for 300x used (sweep 713)
1787	19 March	S	Sw	Guest: Mr. Bryant (Uranus moons)
1787	12 April	S	Sw	Guest: Theophilus Hastings, Robert Jocelyn (Uranus)
1787	April-October	S	Sw	Guest: Jacob Herschel
1787	June	S	Sw	Caroline opened the 'Temporary Index'
1787	July	S	Sw	Guest: Marc Auguste Pictet
1787	7 August	S	Sw	Caroline discovered her last object: NGC 7380
1787	19 August	S	Sw	Discovery of Enceladus with 20-ft
1787	23 August	S	Sw	George III grants £2000 for 40-ft, £200 p.a. for expenses and £50 p.a. for Caroline
1787	Autumn	S	Sw	William and Mary Pitt engaged
1787	19 September	S	Sw	Guest: Jan Śniadecki, Jacob Herschel (Uranus)
1787	September	S	Sw	Herschel's bust was taken by Lochée.
1787	18 October	S	Sw	Sweeping with the double eye glass
1787	26 November	S	Sw	Guest: Méchain, Jean Dominique Cassini, Adrien-Marie Legendre, Simon Carochez
1788	11 March	S	Sw	Guest: William Watson, William Marsden
1788	8 April	S	Sw	Guest: Richard Watson (lunar volcano)
1788	8 May	S	Sw	William married Mary; Caroline moved to the cottage; diaries were destroyed
1788	2 August	S	Sw	Guest: Francis Wollaston
1788	5 August	S	Sw	Guest: Henry Temple, Joseph-Jerome de Lalande
1788	6 August	S	Sw	Guest: Edward Pigott
1788	28 October	S	Sw	Trial sweep of 40-ft
1788	4 November	S	Sw	Reference stars taken from Wollaston's catalogue (sweep 881)

Year	Date	Site	Obs	Event
1788	15 November	S	Sw	William's 50th birthday
1788	3 December	S	Sw	Discovery of object no. 2000 (sweep 889)
1788	21 December	S	Sw	Caroline's 2nd comet
1789	11 April	S	Sw	Guest: Salvador Jiménez Coronado
1789	14 May	S	Sw	Guest: Thomas Bulkeley
1789	11 June	S	Sw	Paper read: second catalogue of nebulae and star clusters
1789	28 August	S	Sw	40-ft operational; NGC 7441 and Enceladus discovered
1789	8 September	S	Sw	Discovery of Mimas with 20-ft
1789	17 September	S	Sw	Mimas observed in 40-ft
1789	20 October	S	Sw	First regular sweep with the 40-ft
1789	12 November	S	Sw	Paper read: Mimas and Enceladus
1789	2 December	S	Sw	Second regular Sweep with the 40-ft
1790	7 January	S	Sw	Caroline's 3rd Comet
1790	18 January	S	Sw	Guest: James Lind, Tiberius Cavallo
1790	16 March	S	Sw	Caroline's 40th birthday
1790	17 April	S	Sw	Caroline's 4th Comet
1790	13 May	S	Sw	Caroline used large sweeper
1790	5 June	S	Sw	Guest: Alexis-Marie de Rochon, Moritz v. Brühl, Alexander Aubert
1790	8 August	S	Sw	Guest: Peter Ungeschick
1790	9 October	S	Sw	Eyepiece for 360x used (sweep 971)
1790	9 October	S	Sw	Most southern objects discovered in Fornax (sweep 972); elevation 6.6°
1790	22 October	S	Sw	William watched a lunar eclipse
1790	13 November	S	Sw	The 'star with an atmosphere' discovered in Taurus, NGC 1514 (sweep 980)
1791	10 February	S	Sw	Paper read: nebulous stars
1791	1 March	S	Sw	Guest: Stephen George Demainbray (Uranus)
1791	11 March	S	Sw	Guest: Michał Poniatowski (brother of King of Poland)
1791	2 April	S	Sw	Sweep 1000 performed
1791	3 April	S	Sw	First solar eclipse watched
1791	27 May	S	Sw	Third regular sweep with the 40-ft
1791	19 July	S	Sw	Caroline opened 4th Journal, recording observations with the large sweeper
1791	28 September	S	Sw	First sweep in the Ecliptic with the 40-ft
1791	18 October	S	Sw	Guest: John Brinkley
1791	23 October	S	Sw	Guest: Bertie Greatheed and his brother (Saturn, 40-ft)
1791	15 December	S	Sw	Caroline's 5th Comet
1791	26 December	S	Sw	Guest: Johann Friedrich Blumenbach
1792	12 January	S	Sw	Guest: Karl Felix v. Seyffer (Saturn)
1792	14 February	S	Sw	*Review No. 5* opened
1792	7 March	S	Sw	John's birth
1792	20 April	S	Sw	Arcturus in the 20-ft (sweep 1021)
1792	29 May	S	Sw	Leisure tour to northern England and Scotland until 29 July (28 days)
1792	15 June	S	Sw	Guest (of Caroline): Joseph Haydn
1792	23 June	S	Sw	Jacob Herschel died by strangulation in Hanover
1792	3 July	S	Sw	William receives the honorary doctoral degree from Glasgow University
1792	19 August	S	Sw	Gallery of 20-ft broke down (sweep 1023)
1792	13 September	S	Sw	Guest: Joah Bates (Saturn)
1793	30 April	S	Sw	William naturalized by an Act of Parliament
1793	5 September	S	Sw	Second solar eclipse watched

Year	Date	Site	Obs	Event
1793	10 September	S	Sw	Guest: Patrick Wilson
1793	27 September	S	Sw	Lowest elevation of 20-ft: 5.1° (ι PsA)
1793	7 October	S	Sw	Caroline's 6th Comet
1794	22 March	S	Sw	First galaxy near Uranus discovered
1794	1 April	S	Sw	Second galaxy near Uranus discovered
1794	18 October	S	Sw	Sweep break starts (sweep 1063)
1794	November	S	Sw	Guest: Giambattista Rodella
1795	28 March	S	Sw	Observations for a new brightness scale started
1795	3 April	S	Sw	William's trip to southwest England (20 days)
1795	11 June	S	Sw	Paper read: construction of the 40ft
1795	7 November	S	Sw	Caroline's 7th Comet
1796	25 February	S	Sw	Paper read: first catalogue of comparative brightness of stars
1796	4 March	S	Sw	Third galaxy near Uranus discovered
1796	9 June	S	Sw	Paper read: second catalogue of comparative brightness of stars
1797	24 January	S	Sw	Reflector: 25-ft /24-in ('Spanish telescope')
1797	18 May	S	Sw	Paper read: third catalogue of comparative brightness of stars
1797	1 June	S	Sw	Caroline finished manuscript of her book, published 1798
1797	24 August	S	Sw	Caroline's 8th Comet
1797	25 August	S	Sw	Caroline's *Book of Observations* ended
1797	October	S	Sw	Caroline left the Observatory House, Slough
1797	22 November	S	Sw	Sweep break ends
1798	15 November	S	Sw	William's 60th birthday
1798	December	S	Sw	Caroline's book on Flamsteed stars published by the *Royal Society*
1799	21 February	S	Sw	Paper read: fourth catalogue of comparative brightness of stars
1799	June	S	Sw	*Sweep records No. 1* started (Caroline's recalculation of sweeps, starting with 46)
1799	19 August	S	Sw	Caroline visits Nevil Maskelyne at Greenwich (about 7 days)
1799	2 September	S	Sw	Guest: Samuel Vince (3 days)
1799	10 September	S	Sw	*Journal No. 12* closed
1799	21 November	S	Sw	Paper read: power of penetrating into space
1800	7 March	S	Sw	Paper read: thermal radiation
1800	16 March	S	Sw	Caroline's 50th birthday
1800	4 July	S	Sw	Caroline stayed in Bath (4 months)
1801	2 April	S	Sw	William's mystery sweep 1096 in Draco
1801	7 August	S	Sw	William's trip to Wales/England (23 days)
1801	2 September	S	Sw	Piazzi's letter on Ceres received
1801	4 September	S	Sw	'Review of the Ecliptic' started
1801	24 September	S	Sw	Bode's *Uranographia* and star catalogue received
1802	3 January	S	Sw	Review of the Ecliptic (asteroid search) ended
1802	3 February	S	Sw	Ceres observed
1802	7 March	S	Sw	John's 10th birthday
1802	21 April	S	Sw	Pallas observed
1802	6 May	S	Sw	Paper read: Ceres and Pallas; term asteroid coined
1802	22 May	S	Sw	Guest: Charles Stanhope, Cornelius Varley
1802	1 July	S	Sw	Paper read: third catalogue of nebulae and star clusters
1802	13 July	S	Sw	William visited Paris (1 month), meeting Messier, Laplace and Napoleon Bonaparte
1802	30 September	S	Sw	Last sweep (1112); last object discovered (NGC 2650); *Sweep records No. 8* ended
1802	October	S		Caroline's 'General Catalogue of new Nebulae and clusters of Stars'

Year	Date	Site	Obs	Event
1802	9 November	S		William watched his second Mercury transit
1802	December	S		Caroline's table '2500 Nebulae and Clusters of Stars'
1803	30 March	S		Sophia Herschel died in Hanover
1803	21 June	S		Solar apex determined
1803	29 September	S		Juno observed
1804	11 February	S		Third solar eclipse watched
1804	16 March	S		Revised sweep records finished (on Caroline's 54th birthday)
1804	October	S		'Spanish telescope' delivered
1805	8 December	S		Comet Biela watched
1806	27 February	S		Paper read: second on motion of the Sun
1806	16 June	S		Fourth solar eclipse watched
1806	9 July	S		Guest: Dietrich Herschel (Saturn)
1807	5 April	S		Guest: Joanna Baillie
1807	22 May	S		Vesta observed
1807	18 June	S		Guest: James and Ann Watt
1807	18 August	S		Guest (of Caroline): Prince Edward, Louis Phillipe II
1807	2 October	S		Caroline observed the Great Comet of 1807
1807	4 October	S		Guest: Ernst zu Münster, Gen. Cartwright, Mrs. & Miss Beckedorff (comet)
1807	7 October	S		Guest: James Lind (comet)
1807	14 October	S		Guest: Prince Augustus Frederick + 50 persons!
1807	19 October	S		Guest: Shute Barrington, Lady F. Murry, George Legge (comet)
1807	9 November	S		Last observation of the Moon
1808	3 February	S		Guest: Prince Adolphus Frederick (40-ft)
1808	15 November	S		William's 70th birthday
1809	12 January	S		Last observation of Jupiter (7-ft)
1810	16 March	S		Caroline's 60th birthday
1810	25 May	S		Last observation of Uranus (40-ft)
1810	13 July	S		Journey to Scotland (2 months)
1811	13 March	S		Last sketch of M 42
1811	20 June	S		Paper read: first on astronomical observations
1811	24 August	S		Reflector: 20-ft / 24-in ('X-feet')
1811	2 September	S		William's trip to Glasgow (16 days)
1811	4 September	S		Caroline observed the Great Comet of 1811
1811	8 September	S		Guest: Dietrich Herschel (comet), new 'night glass' used
1811	9 September	S		Guest: William and Mary Harcourt (comet)
1811	18 September	S		Guest: Prince Adolphus Frederick (comet)
1811	19 October	S		Guest: Dietrich Herschel (Comet note)
1812	1 January	S		Comet Pons watched
1813	14 May	S		Additional sweep 1113 with 20-ft
1813	31 May	S		*Sweeps No. 7* closed
1813	July-August	S		Guest: Dietrich Herschel
1813	15 December	S		Last observations of Venus and Mars
1814	24 February	S		Paper read: second on astronomical observations
1814	October	S		Last observation of Saturn, finally using the 40-ft
1815	28 March	S		'Hurricane' at Slough
1815	29 March	S		Comet Olbers watched
1816	4 April	S		William received the Royal Hanoverian Guelphic Order

Year	Date	Site	Obs	Event
1816	15 September	S		Alexander moves from Bath to Hanover
1816	12 October	S		John's first observation (double stars with the 7-ft)
1816	October	S		Caroline started work on the *Zone Catalogue*
1817	19 June	S		Paper read: third on astronomical observations
1817	29 July	S		Caroline's 'Temporary Index' closed
1818	Spring	S		William received the Coat of Arms
1818	11 June	S		Paper read: fourth on astronomical observations
1818	15 November	S		William's 80th birthday
1819	3 July	S		William observed the Great Comet of 1819
1819	4 July	S		*Review No. 8* closed
1819	7 September	S		William's last observation (comet Tralles)
1819	5 December	S		William's last entry in 'Experiments' (20-ft mirror)
1820	10 March	S		Foundation of the Astronomical Society of London (William first titular President)
1820	16 March	S		Caroline's 70th birthday
1821	1 February	S		Manuscript of third double star catalogue finished
1821	March	S		John started systematic observations of double stars (with James South)
1821	16 March	S		Alexander Herschel died in Hanover
1821	29 May	S		John made trial sweeps with the 20-ft, recorded by Caroline
1822	7 March	S		John's 20th birthday
1822	25 August	S		William Herschel died in Slough at the age of 83
1822	28 October	H		Caroline moved to Hanover
1824	31 January	H		Caroline watched the Great Comet of 1823
1824	early	H		Caroline continued work on *Zone Catalogue*
1825	March	H		Caroline finished work on Zone Catalogue
1827	19 January	H		Dietrich Herschel died at Hanover
1828	28 February	H		Caroline received *Gold Medal* of *Astronomical Society of London* for *Zone Catalogue*

1124 He was the father of Fanny Burney, guest of the Herschels in 1786 and 1787.

Index

Page number format: normal = text, bold = figure (caption), underlined = table (caption), italics = footnote.

Persons

William and Caroline Herschel are too frequent, so they do not appear here (except for portraits); however, but John is listed. Literature quotes in the footnotes, e.g. Lubbock (1933), are not included. For objects (Bode's Nebulae, Comet Halley etc.), see the Object Index. For terms like *Messier Catalogue*, see the Subject Index.

Abell, George Ogden (1927–1983) →, →, →
Aratos (315–245 B.C.) →, →
Argelander, Friedrich Wilhelm (1799–1875) →
Aristoteles (384–322 B.C.) →, →
Arnold, John (1736–1799) →, →, →, →
Arp, Halton (1927–2013) →, →, →
Artaud, William (1763–1823) →
As-Sufi, Abd-al-Rahman (903–986) →, →
Aubert, Alexander (1730–1805) →, →, →, →, →, →, →, →, →, →, →, →, →
Auwers, Georg Friedrich Julius Arthur v. (1838–1915) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Bailey, Solon Irving (1854–1931) →, →, →
Baillie, Joanna (1762–1851) →, →
Baily, Francis (1774–1844) →, →, →, →, →
Baldwin, Sophia (1783–1820) →, →
Banks, Joseph (1743–1820) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Barnard, Edward Emerson (1857–1923) →, →, →, →, →, →
Barrington, Shute, Bishop of Salisbury (1734–1826) →

Bates, Joah (1741–1799) →, →, →
Bayer, Johann (1572–1625) →, →, →, →, →, →, →, →, →, →, →
Beckedorff, Charlotte Amalie (†1840) →, →
Bellamy, Frank Arthur (1863–1936) →
Bessel, Franz Friedrich Wilhelm (1784–1846) →, →, →, →
Bevis, John (1695–1771) →, →
Biela, Wilhelm v. (1782–1856) →
Bigourdan, Guillaume (1851–1932) →, →, →, →, →
Bird, John (1709–1776) →
Birmingham, John (1816–1884) →
Blagden, Charles (1748–1820) →, →, →, →, →, →, →, →, →, →, →–→
Blair, Robert (1748-1828) →
Blaeu, Willem Janszoon (1571–1638) →, →
Blumenbach, Johann Friedrich (1752–1840) →, →
Bode, Johann Elert (1747–1826) →, →
Bonaparte, Lucien (1775–1840) →
Bonaparte, Napoleon (1749–1827) →, →, →
Bouvard, Alexis (1767–1843) →
Bradley, James (1692–1762) →, →, →
Brahe, Tycho (1546–1601) →
Brewster, David (1781–1868) →
Brinkley, John (1763–1835) →, →, →
Brühl, Hans Moritz v. (1736–1809) →, →, →, →, →, →
Bryant (Mr.) →, →
Brydone, Patrick (1736–1818) →, →
Bulkeley, Thomas (1752–1822) →, →
Burney, Charles (1726–1814) →
Burney, Frances [Fanny] (1752–1792) →, →, →
Campion (workman) →, →, →

Carochez, Noël Simon (1740–1813) →, →
Cartwright (General) →, →
Cassini, Giovanni Domenico (1625–1712) →, →, →, →, →, →
Cassini, Jean Dominique (1748–1845) →, →, →, →, →, →
Castelli, Benedetto (1578–1643) →, →
Cavallo, Tiberius (1749–1849) →, →
Cavendish, Henry (1748–1820) →, →, →, →
Chambers, George Frederik (1814–1915) →
Charles IV, King of Spain of Spain (1748–1819) →, →, →
Chéseaux, Jean Phillippe Loys de (1718–1751) →, →, →, →, →, →, →, →, →, →, →, →
Chief Bowles (1765–1839) →
Chreptowicz (1729–1812) →
Christie, William Henry Mahoney (1845–1922) →
Clerke, Agnes Mary (1842–1907) →, →, →, →
Collinder, Per (1890–1975) →, →, →
Collins (Mr.) →, →
Copeland, Ralph (1837–1905) →
Coutel, Antoine Gaspard Marius (1814-1886) →
Darquier de Pellepoix, Antoine (1822–1875) →, →
D‘Arrest, Heinrich Louis (1822–1875) →, →, →, →, →, →, →, →, →, →, →, →–→, →
Deluc, Jean-André (1727–1817) →
Demainbray, Stephen Charles (1710–1782) →, →
Demainbray, Stephen George (1760–1854) →, →, →, →
Dolland, John (1706–1761) →, →, →, →, →, →
Dreyer, John Louis Emil (1852–1926) →, →, →, →, →–→, →, →, →–→, →, →, →, →, →, →, →, →, →, →–→, →–→, →,

→, →, →, →, →, →, →, →, →,
→, →, →, →, →, →, →, →, →,
→, →, →, →–→, →, →, →, →
Dunlop, James (1793–1848) →, →, →, →
Encke, Johann Franz (1791–1865) →, →
Henry Charles Englefield (1752–1822) →, →
Ernest II, Duke of Saxe-Gotha (1745–1804) →, →
Espin, Thomas Henry Espinell Compton (1858–1934) →
Fabricius, David (1564–1617) →, →
Faujas de Saint-Font, Barthélemy (1741–1819) →, →, →–→, →, →, →
Ferguson, James (1710–1776) →, →, →, →, →, →, →, →, →, →,
→, →, →, →, →, →, →, →
Flammarion, Nicolas Camille (1842–1925) →
Flamsteed, John (1646–1719) →, →, →, →, →, →, →, →, →, →,
→, →, →, →, →, →, →, →, →,
→, →, →, →, →–→, →, →, →,
→, →, →, →, →, →, →, →, →,
→, →, →, →, →, →
Fleming, Williamina (1857–1911) →
Fortin, Jean Niclas (1750–1831) →
Friedrich Willhelm IV, King of Prussia (1795–1861) →
Galilei, Galileo (1564–1662) →
Gallitzin, Demetrius Augustine (1770–1840) →
Gauss, Carl Friedrich (1777–1855) →
Gemma, Cornelius (1535–1577) →
George III, King of Great Britain and Ireland (1783–1820) →, →, →, →, →, →, →, →, →, →,
→, →, →–→
Gingerich, Owen (*1930) →, →, →, →
Glyn Jones, Kenneth (1915–1995) →, →, →, →
Goodricke, John (1764–1786) →
Gordon, Alexander (1743–1827) →, →
Greatheed, Bertie (1759–1826) →, →
Gregory, Edward (1744–1824) →, →

Grévedon, Henri (1776–1860) **frontispiece**
Griesbach, George Ludolf Jacob (1757–1824) →, →
Groombridge, Stephen (1755–1832) →
Guntermann, Marie Sophie (1730–1807) →, →
Hagen, Johann Georg (1847–1930) →, →, →, →, →
Hahn, Friedrich v. (1742–1805) →
Halley, Edmond (1656–1742) →, →, →, →, →
Harcourt, William, 3rd Earl Harcourt (1743–1830) →, →
Harcourt, Mary (1750–1833) →, →
Harding, Karl Ludwig (1765–1834) →, →, →, →
Harris, Joseph (1702/03–1764) →, →, →
Hastings, Theophilus Henry, 11th Earl of Huntingdon (1728–1804) →, →
Hawkings (Mr.) →, →
Haydn, Franz Joseph (1732–1809) →, →, →
Heberden, William (1710–1801) →, →, →
Hell, Maximilian (1720–1792) →
Herschel, Anna Elisabeth (1783–1872) →, →
Herschel, Caroline Lucretia (1750–1848) →, →, →
Herschel, Col. John (1837–1921) →, →, →
Herschel, William (1738–1822) **frontispiece**, →, →, →, →
Herschel, Heinrich Anton Jacob (1734–1792) →, →, →, →, →, →
Herschel, Johann Alexander (1745–1821) →, →–→, →, →
Herschel, Johann Dietrich (1755–1827) →, →, →, →, →, →, →, →, →, →, →, →, →, →
Herschel, John Frederick William (1792–1871) →, →, →, →, →, →, →, →, →, →, →, →, →, →–→, →, →–→, →, →, →, →, →, →, →, →, →, →–→, →,

→, →, →, →, →, →–→, →, →–
→, →, →, →, →, →, →, →, →–
→, →, →, →, →, →, →, →, →–
→, →, →, →–→, →, →, →, →,
→, →–→, →–→, →, →, →, →–
→
Herschel, Mary [Lady Herschel, neé Pitt] (1750–1832) →, →, →, →, →, →, →, →, →, →, →, →, →, →
Herschel, Mary Brodie [neé Stewart] (1810–1884) →, →
Herschel, Mary Cornwallis [Mrs. John] (1829–1876) →, →, →
Herschel, Matilda Rose (1844–1914) →, →
Herschel, Sophia Elisabeth (1733–1803) →, →, →, →
Herschel, William James (1833–1917) →, →
Herschel-Shorland, John (1935–2017) →
Hevelius, Johannes (1564–1617) →, →, →, →, →, →, →, →, →
Hickson, Paul (*1823) →, →
Hind, John Russell (1823–1895) →, →, →, →, →
Hipparchus (190–125 B.C.) →, →, →
Hodierna, Giovanni Battista (1597–1660) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Hohenbaum, Gottfried (1785–1857) →
Holden, Edward Singleton (1846–1914) →, →, →
Hooke, Robert Hooke (1635–1703) →
Hornsby, Thomas (1733–1810) →, →, →
Hoskin, Michael (*1930) →
Howard, John (1739–1820) →, →
Hubble, Edwin Powell (1889–1953) →, →, →
Huggins, William (1824–1910) →
Humboldt, Alexander v. (1769–1859) →
Hutton, Charles (1737–1823) →, →, →

Huygens, Christiaan (1629–1695) →, →, →, →, →, →, →, →
Ihle, Johann Abraham (1627–1699) →
Irby, Frederick Paul (1779–1844) →
Javelle, Stephane (1864–1917) →, →
Jiménez Coronado, Salvador (1747–1813) →, →, →
Jocelyn, Robert, 2nd Earl of Roden (1756–1820) →, →
Jones, Thomas (1756–1807) →
Kapteyn, Jacobus Cornelius (1851–1922) →
Kepler, Johannes (1571–1630) →
King, Ivan Robert (*1927) →
Kirch, Gottfried (1639–1710) →, →, →, →, →, →, →, →
Kirch, Maria Margaretha (1670–1720) →
Koehler, Johann Gottfried (1745–1801) →, →, →, →
Komarzewski, Jean-Baptiste (1744–1810) →, →
Lacaille, Nicolas-Louis de (1713–1762) →, →, →, →, →, →, →, →, →, →
Lalande, Joseph-Jerome le Francois de (1732–1807) →, →, →, →, →, →, →, →, →
Laplace, Pierre-Simon de (1749–1827) →, →, →
Lassell, William (1799–1880) →, →
Laugier, Paul-Auguste-Ernest (1812–1872) →
Lax, William (1761–1836) →
Le Gentil, Guillaume Hyazinthe (1725–1792) →
Lee, Stephen (1770–1835) →, →
Legendre, Adrien-Marie (1752–1833) →, →, →
Legge, George, Viscount Lewisham (1755–1810) →, →
Lemaire, Jacques (1676–1746) →
Lennox, Charles (1764–1819) →

Lexell, Anders Johan (1740–1784) →
Liddell, Anne (1712–1794) →
Lind, James (1736–1812) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Lochée, John Charles (1751–1791) →, →, →
Lord Rosse; see Parsons, William
Louis Phillipe II, Duke of Orléans (1773–1850) →, →
Lubbock, Constance Anne (1855–1939) →, →
Luther, Eduard (1816–1887) →, →
Lynds, Beverley Turner (*1929) →
Magellan, Jean Hyacinthe de (1723–1790) →, →, →
Mairan, Jean Jacques d'Ortous de (1678–1771) →, →, →
Mallas, John (1927–1975) →
Maraldi, Jean-Dominique (1709–1788) →, →
Markarian, Benjamin (1913–1985) →
Marsden, William (1754–1836) →, →, →
Marth, Albert (1828–1897) →, →
Maskelyne, Nevil (1732–1811) →, →, →, →, →, →, →, →, →–→, →, →, →, →, →, →
Maskelyne, Sophia (1752–1821) →
Maurer, Andreas (1932–2013) →
Mayer, Christian (1719–1783) →, →, →, →, →, →
Mayer, Tobias (1723–1762) →, →, →, →, →, →, →, →, →, →
Maximilian Joseph von Österreich-Este (1782–1863) →
Méchain, Pierre Francois Andre (1744–1804) →, →–→, →, →
Messier, Charles-Joseph (1730–1817) →, →, →, →, →, →–→ →, →–→, →, →, →, →, →, →, →–→, →, →, →, →, →, →, →, →, →, →, →, →, →–→, →, →, →,

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Mitchel, Ormsby MacKnight (1809–1862) →
Mitchel, R. J. →, →
Mitchell, John (1724–1793) →, →, →, →, →, →, →
Montagu, George, 1. Duke of Montagu (1712–1790) →, →
Montanari, Geminiano (1633–1687) →
Motte, Andrew (1696–1734) →
Münster, Ernst zu (1766–11839) →, →
Murry (Lady) →, →
Nairne, Edward (1726–1806) →, →, →, →
Newton, Isaac (1643–1727) →, →, →, →
Noble, William (1882–1904) →
Oeynhausen, Countess Leonor v. (1750–1839) →
Oeynhausen, Georg Ludwig v. (1734–1811) →
Olbers, Heinrich Wilhelm Matthias (1758–1840) →, →, →, →
Oriani, Barnaba (1752–1832) →, →, →, →
Papendiek, Charlotte Louise Henrietta (1762–1840) →
Papendiek, Christopher (1755–1826) →
Parr, William Alfred (1834–1936) →
Parsons, Lawrence, 4th Earl of Rosse (1840–1908) →, →, →
Parsons, William, 3rd Earl of Rosse [Lord Rosse] (1800–1867) →, →
Peiresc, Nicolas-Claude Fabri de (1580–1637) →, →
Percy (Earl) →
Pfaff, Johann Wilhelm Andreas (1774–1835) →, →, →, →
Phips (Dr) →
Piazzi, Giuseppe (1746–1826) →, →, →, →, →, →, →
Picard, Jean (1620–1682) →

Pickering, Edward Charles (1846–1919) →, →
Pictet, Marc Auguste (1752–1825) →, →
Pigott, Edward Charles (1753–1825) →, →, →, →, →, →, →, →, →
Plana, Giovanni Antonio Amedeo (1781–1864) →
Plaskett, John Stanley (1865–1941) →
Playfair, John (1748–1819) →, →
Poniatowski, Michał Jerzy (1736–1794) →, →
Pons, Jean Louis (1761–1831) →, →
Prince Adolphus Frederick, 1st Duke of Cambridge (1774–1850) →, →
Prince Augustus Frederick, Duke of Sussex (1773–1843) →, →
Prince Charles, Duke of Mecklenburg-Strelitz (1741–1816) →, →
Prince Edward, Duke of Kent and Strathearn (1767–1820) →, →
Prince William (1765–1837) →, →
Ptolemy, Claudius (87–165) →, →, →, →, →, →
Rackett, Thomas (1755–1840) →
Ramage, John (1788–1835) →, →
Reinmuth, Karl Wilhelm (1892–1979) →, →
Riccioli, Giovanni (1598–1671) →
Richardson (General) →
Rigolett, Roger (1909–1981) →, →
Roberts, Isaac (1829–1904) →, →
Robinson, Thomas Romney (1792–1882) →, →
Rochon, Alexis-Marie de (1741–1817) →, →, →
Rodella, Giambattista (1749–1834) →, →
Safford, Truman Henry (1836–1901) →, →
Sawyer-Hogg, Helen (1905–1993) →, →
Schmidt, Johann Friedrich Julius →

(1825–1884)
Schroeter, Johann Hieronymus (1745–1816) →, →, →, →
Secchi, Pietro Angelo (1818–1878) →, →, →
Senex, John (1678–1740) →, →, →, →
Seyffer, Karl Felix v. (1762–1822) →, →, →
Shapley, Harlow (1885–1972) →, →, →
Shelton, John (1712–1777) →
Shepherd, Anthony (1721–1796) →, →, →
Shoemaker, Carolyn (*1929) →
Short, James (1710–1768) →, →
Smeaton, John (1724–1792) →, →, →, →
Smith, Robert (1689–1768) →, →, →, →, →, →
Smyth, William Henry (1788–1865) →, →, →
Śniadecki, Jan (1756–1830) →, →, →
Sophie Charlotte, Queen of Great Britain and Ireland (1744–1818) →, →, →, →, →, →, →
South, James (1785–1867) →, →, →, →, →, →
Sprat (workman) →
Stanhope, Charles (1753–1816) →, →
Steavenson, William Herbert (1894–1975) →, →
Steinicke, Wolfgang (*1952) →, →
Stephan, Édouard Jean-Marie (1837–1923) →, →
Stock, Jürgen (1923–2004) →
Stoney, Bindon Blood (1829–1909) →, →, →
Stoney, George Johnstone (1826–1911) →, →, →, →, →, →
Storker (Lord) →
Struve, Friedrich Georg Wilhelm v. (1793–1864) →, →, →, →, →, →, →, →, →
Struve, Otto Wilhelm v. (1819–1905) →
Swift, Lewis (1820–1913) →, →, →, →
Tempel, Ernst Wilhelm Leberecht (1821–1889) →, →
Temple, Henry [Lord Palmerston] (1739–1802) →, →

Tralles, Johann Georg (1763–1822) →
Trouvelot, Étienne Leopold (1827–1895) →
Trümpler [Trumpler], Robert (1886–1956) →, →, →
Ungeschick, Peter (1760–1790) →, →, →, →
Van den Bergh, Sidney (*1929) →
Varley, Cornelius (1781–1873) →, →
Vince, Samuel (1749–1821) →, →, →
Warner, Brian (*1939) →
Watson, Richard (1737–1816) →, →
Watson, William Jr (1744–1825) →, →, →, →, →, →–→, →, →, →, →, →, →, →, →, →, →, →
Watson, William Sr (1715–1787) →
Watt, Ann (1738–1832) →, →
Watt, James (1736–1819) →, →, →
Webb, Thomas William (1807–1885) →, →
White (Miss) →, →
Wilson, Patrick (1743–1811) →, →, →, →, →, →, →, →, →, →
Winnecke, Friedrich August Theodor (1835–1897) →, →, →, →
Wolf, Maximilian Franz Josef Cornelius (1863–1932) →, →, →, →, →, →
Wollaston, Francis John Hyde (1731–1815) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Zach, Franz Xaver v. (1754–1832) →, →, →, →
Zucchi, Niccolò (1586–1670) →
Zwicky, Fritz (1889–1974) →

Objects

Nebulae and star clusters: names

Andromeda Nebula →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Barnard’s Loop →, →
Barnard’s Star →
Bear Paw Galaxy →, →

Black Eye Galaxy →, →, →, →
Blinking Planetary →, →
Blue Flash Nebula →, →, →, →
Blue Snowball →, →, →, →, →, →
Bode’s Nebulae →, →, →, →
Bubble Nebula →
Butterfly Cluster →, →, →, →, →
Cat Eye Nebula →, →, →
Cetus Cluster →
Christmas Tree Cluster →, →, →
Coma Berenices Cluster →
Coma Cluster →, →, →, →, →, →
Cone Nebula →
Crab Nebula →, →, →, →, →
Crescent Nebula →
Double Cluster →, →, →, →, →, →, →, →, →, →, →, →
Draco Chain →
Dumbbell Nebula →, →, →, → →, →
Eagle Nebula →
Emberson-Jones 1 →
Eskimo Nebula →, →, →
Eye of Sagittarius →, →
Flame Nebula →, →, →
Galaxy →
Ghost of Jupiter →, →, →, →
Great Rift →, →
Helix Nebula →, →
Hind’s Variable Nebula →
‘hole in Scorpius’ →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Horsehead Nebula →, →
Hubble’s Variable Nebula →, →, →
Hyades →, →, →, →
Ink Spot →
JH’s cluster →
Keyhole Nebula →
Lagoon Nebula →, →, →, →, →, →, →, →
Leo Cluster →, →, →
Leo Triplet →

Little Dumbbell →, →, →, →, →, →
Little Gem →, →
Local Group →, →, →, →, →
M 105 trio →
Magellanic Clouds →
Markarian Chain →
Merope Nebula →
Milky Way →, →
NGC 68 group →, →
North America Nebula →, →, →, →, →, →
Omega Nebula →, →, →
Orion Nebula →, →
Owl Nebula →, →, →, →
Pegasus I Cluster →, →
Perseus Cluster →, →
Pickering's Triangular Wisp →, →
Pinwheel Galaxy →, →
Pleiades →, →, →, →, →, →, →, →, →, →, →, →
Polarissima Borealis →
Praesepe →, →, →, →, →, →, →, →, →, →, →, →
Ptolemy's Cluster →, →, →, →, →
Ring Nebula →, →, →, →, →, →
Sagittarius Star Cloud →, →, →, →
Saturn Nebula →, →, →, →, →, →
Sculptor Galaxy →, →, →, →, →, →
Scutum Star Cloud →, →
Siamese Twins →
Silver Dollar Galaxy →
Sombrero Galaxy →, →, →, →
Spindle Galaxy →
Stephan's Quintet →
Sunflower Galaxy →, →, →

The Antennae →, →, →, →
The Box →, →, →
The Eyes →
The Mice →, →
Triangulum Nebula Trifid Nebula →, →, →, →, →, →, → →, →, →, →, →, →, →, →, →, →, →
Veil Nebula →, →, →, →, →, →, →, →, →, →, →, →, →, →
Via Lactea →, →, →
Virgo Cluster →, →, →, →
Whirlpool Nebula →, →, →, →
WH's cluster →
Wild Duck Cluster →, →, →, →, →
ε Orionis Nebula →, →
Η Carinae Nebula →
ι Orionis Nebula →, →, →, →, →, →
ρ Ophiuchi Nebula →

Nebulae and star clusters: catalogues

(for the designations see Abbreviations)

3C 273 →
Abell 194 →, →
Abell 262 →, →, →, →
Abell 347 →, →
Abell 426 →, →
Abell 1185 →, →
Abell 1367 →, →, →
Abell 1656 →, →
Abell 2197 →
Abell 2199 →, →, →
Arp 318 →, →
Auwers 16 →
Auwers 41 →
Auwers 48 →
B 7 →
B 19 →
B 41 →
B 42 →

B 44 →
B 78 →
B 86 →, →, →
B 229 →
Ced 21 →, →, →
Cr 115 →, →, →
DG 11 →
GC 708 →
GC 709 →
GC 1618 →
GC 1857 →
GC 1949 →
GC 1950 →
GC 1953 →
GC 2034 →
GC 2258 →
GC 2730 →
GC 2734 →
GC 2821 →
GC 2878 →
GC 3020 →
GC 3021 →
GC 3022 →
GC 3023 →
GC 3146 →, →
GC 3147 →
GC 3174 →
GC 3228 →
GC 3302 →
GC 3506 →
GC 3582 →
GC 3583 →
GC 3746 →
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GC 3849 →
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GC 5653 →
GC 5654 →
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h 170	→
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h 373	→
h 392	→
h 484	→
h 603	→
h 612	→, →
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h 1061	→
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h 1125	→
h 1159	→
h 1202	→, →
h 1293	→, →, →
h 1294	→
h 1294a	→
h 1332	→, →
h 1383	→
h 1384	→, →
h 1385	→
h 1474	→, →
h 1627	→
h 1628	→
h 1730	→
h 1767	→
h 1781	→
h 1834	→
h 1945	→

h 2000 →
h 2004 →
h 2038 →
h 2048 →
h 2055 →
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h 2100 →
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h 2251 →
h 2276 →
h 2296 →, →
h 3112 →
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h 3181 →
h 3725 →
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MCG -3-25-18	→, →
MCG -2-6-52	→
MCG -2-33-61	→
MCG -1-24-1	→, →
MCG -1-35-7	→, →
MCG 5-29-24	→, →, →, →
MCG 7-32-44	→
MCG 9-22-20	→, →
MCG 10-16-61	→, →, →
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Mrk 205	→
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NGC 7507 →, →, →, →, →, →
NGC 7537 →
NGC 7538 →, →
NGC 7541 →
NGC 7562 →
NGC 7585 →, →, →
NGC 7618 →, →, →
NGC 7619 →, →
NGC 7623 →
NGC 7626 →
NGC 7634 →
NGC 7635 →, →, →
NGC 7640 →
NGC 7648 →
NGC 7653 →
NGC 7662 →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
NGC 7664 →
NGC 7671 →
NGC 7681 →
NGC 7686 →
NGC 7703 →
NGC 7714 →
NGC 7715 →
NGC 7760 →
NGC 7762 →
NGC 7769 →
NGC 7770 →, →
NGC 7771 →
NGC 7772 →
NGC 7778 →
NGC 7779 →
NGC 7782 →
NGC 7789 →, →, →, →, →, →

NGC 7800 →
NGC 7805 →, →
NGC 7806 →, →
NGC 7810 →, →, →, →
NGC 7814 →
Palomar 9 →
Stock 8 →
Tr 7 →, →, →
UGC 807 →
UGC 2272 →, →
UGC 3580 →, →
UGC 3696 →, →
UGC 5722 →, →, →
UGC 6697 →
UGC 6728 →, →
UGC 8756 →, →
UGC 8902 →, →, →
UGC 9598 →, →
vdB 68 →, →, →

Stars: double

I 1 →, →, →
I 2 →, →
I 10 →
I 28 →
I 32 →
I 36 →
I 49 →, →
I 50 →
I 57 →
I 94 →
II 1 →
II 5 →
II 6 →
II 10 →
II 11 →
II 17 →
II 19 →
II 22 →

II 26 →, →
II 27 →
II 33 →, →
II 38 →, →
II 63 →
II 71 →, →
II 102 →
III 1 →, →
III 2 →, →
III 12 →
III 13 →
III 14 →
III 22 →
III 23 →, →
III 29 →
III 31 →
III 44 →
III 54 →
III 71 →
III 72 →
III 93 →
III 113 →, →
III 114 →, →, →
IV 1 →
IV 13 →
IV 28 →
IV 48 →, →
IV 60 →
IV 71 →, →
IV 79 →
IV 90 →
IV 129 →
V 1 →
V 5 →
V 14 →, →
V 37 →
V 121 →
V 124 →
VI 1 →
VI 11 →

VI 19 →
VI 42 →
VI 66 →
VII 1 →
N1 →, →
N5 →
N6 →, →, →
N9 →
N10 →, →
N12 →
N16 →
N21 →
N24 →
N27 →
N40 →, →, →, →
N54 →
N55 →
N56 →
N73 →, →
N86 →
N101 →
N118 →, →, →, →
N124 →
N128 →
N133 →
N144 →
N145 →, →

Stars: name

Albireo →, →, →
Alcyone →
Aldebaran →, →, →, →, →, →, →
Algol →, →, →, →
Alioth →, →, →
Alnitak →, →, →
Altair →, →
Antares →, →, →, →, →, →, →
Arcturus →, →, →, →, →, →, →, →, →
Baten Kaitos →

Bellatrix →
Betelgeuse →, →, →, →, →, →
Capella →, →, →, →, →, →
Castor →, →, →, →, →, →, →, →, →, →,
→, →, →
Cor Caroli →, →
Deneb →, →, →
Denebola →, →
Double double star →, →, →
Erakis →
Fomalhaut →, →, →, →, →, →, →, →
Herschel‘s Garnet Star →, →, →, →, →, →, →
Hind‘s Crimson Star →, →, →, →
J. Herschel's Ruby Star →, →
Kapteyn‘s Star →
Kepler‘s supernova →
Kochab →
La Superba Maia →, →, → →
Markab →
Markeb →
Meissa →
Merope →
Mira Mirach →, →, →, →, →, →, →, →, → →,
→
Mirzam →
Mizar →, →, →, →, →, →, →
Nova 1686 →
Nova Vulpeculae →
Orion‘s belt →, →, →
Orion‘s sword →, →, →
Pigott's variable →
Polaris →, →, →, →, →, →, →, →, →, →,
→
Pole star →, →, →
Pollux →, →, →
Porrima →
Procyon →, →, →, →, →, →, →, →, →, →
Ptolemy‘s Eyes →, →, →
Ras Algethi →, →, →
Regulus →, →, →, →, →

Rigel →, →, →, →, →, →, →, →, →, →, →
Saiph →
Sirius →, →, →, →, →, →, →, →, →, →, →, →, →, →
Spica →, →, →, →, →
Trapezium →, →, →, →, →, →, →, →, →, →
Tycho‘s supernova →
Vega →, →, →, →, →, →, →

Stars: constellation

β And →, →, →, →
γ And →, →
ε And →
ν And →, →
σ And →
13 And →
43 And →
55 And →
56 And →
59 And →
π Ant →
α Aql →, →
η Aql →
λ Aql →
ν Aql →
5 Aql →
9 Aql →
12 Aql →, →
14 Aql →
15 Aql →
k Aql →
V Aql →, →, →
ζ Aqr →, →, →
ι Aqr →, →
ν Aqr →, →, →, →
8 Aqr →
30 Aqr →
41 Aqr →, →

88 Aqr →
97 Aqr →
100 Aqr →
107 Aqr →
γ Ari →
ξ Ari →, →
87 Ari →
α Aur →
β Aur →
θ Aur →
λ Aur →
σ Aur →
φ Aur →, →
ε Aur →
6 Aur →
α Boo →, →
ε Boo →, →, →, →, →, →, →
9 Boo →
15 Boo →, →
18 Boo →
31 Boo →, →
7 Cam →
12 Cam →
42 Cam →, →
43 Cam →, →, →
α Cap →, →
β Cap →
γ Cap →
κ Cap →, →
ρ Cap →, →, →
υ Cap →, →
19 Cap →
39 Cap →
42 Cap →
RT Cap →, →, →
γ Cas →, →
δ Cas →
ε Cas →
η Cas →, →
ι Cas →, →

κ Cas →, →
ρ Cas →
σ Cas →
φ Cas →
1 Cas →
2 Cas →
50 Cas →
ω Cen →, →, →
2 Cen →
3 Cen →
δ Cep →, →
ε Cep →
μ Cep →, →, →, →, →, →, →
9 Cep →
ρ Cep →
10 Cep →, →
S Cep →, →, →
V380 Cep →
V419 Cep →, →
α Cet →, →
β Cet →, →
δ Cet →, →, →, →, →, →, →, →
ζ Cet →, →, →, →
θ Cet →, →
ι Cet →, →
κ Cet →
ο Cet →, →, →, →, →, →
τ Cet →
φ1 Cet →, →
2 Cet →
8 Cet →
36 Cet →
37 Cet →
38 Cet →
41 Cet →
67 Cet →
α CMa →
β CMa →
γ CMa →
δ CMa →, →

ρ CMa	→
τ CMa	→, →, →, →
12 CMa	→
29 CMa	→, →
W CMa	→, →
α CMi	→, →
γ CMi	→
α Cnc	→
δ Cnc	→, →
ε Cnc	→
ζ Cnc	→, →
κ Cnc	→
υ1 Cnc	→
ε Cnc	→
12 Cnc	→
RT Cnc	→
β Com	→
γ Com	→
7 Com	→
9 Com	→
10 Com	→
12 Com	→
37 Com	→
R CrB	→
ε Crt	→
θ Crt	→
b Crt	→, →
6 Crt	→, →
α CVn	→
β CVn	→, →, →, →, →
2 CVn	→, →
4 CVn	→, →
13 CVn	→
Y CVn	→, →
α Cyg	→
β Cyg	→, →
γ Cyg	→, →, →, →
δ Cyg	→, →
ε Cyg	→
η Cyg	→, →

υ Cyg	→
ε Cyg	→, →, →, →, →, →
14 Cyg	→, →
17 Cyg	→, →
19 Cyg	→, →
27 Cyg	→
34 Cyg	→
41 Cyg	→
52 Cyg	→, →
61 Cyg	→, →, →, →, →
P Cyg	→, →
V2140 Cyg	→
γ Del	→
ι Dra	→
μ Dra	→
ν Dra	→
17 Dra	→
35 Dra	→
RY Dra	→, →
γ Equ	→
δ Equ	→
3 Equ	→
4 Equ	→
7 Equ	→
ν Eri	→, →, →
39 Eri	→, →
47 Eri	→
69 Eri	→, →
α Gem	→, →
β Gem	→, →
γ Gem	→, →
δ Gem	→, →, →
η Gem	→, →
μ Gem	→, →
ξ Gem	→, →
υ Gem	→
H Gem	→, →, →, →, →, →
1 Gem	→
6 Gem	→, →
48 Gem	→

60 Gem →
79 Gem →
85 Gem →
BU Gem →
α Her →, →, →
β Her →
δ Her →
ζ Her →, →
η Her →
λ Her →, →, →, →, →
π Her →
σ Her →
5 Her →
100 Her →
α Hya →
λ Hya →, →
υ1 Hya →
ω Hya →
1 Hya →
1102 e Hya →
U Hya →, →, →
W Hya →, →
5 Lac →
9 Lac →
V412 Lac →
α Leo →
β Leo →, →, →
γ Leo →, →, →, →
δ Leo →
η Leo →, →
θ Leo →
ι Leo →
ρ Leo →
φ Leo →, →
24 Leo →
31 Leo →
42 Leo →
49 Leo →
50 Leo →, →
52 Leo →

58 Leo →
75 Leo →, →
83 Leo →
92 Leo →
R Leo →
β Lep →, →
γ Lep →, →
ι Lep →
R Lep →, →
12 Lib →
24 LMi →
27 Lyn →
39 Lyn →
42 Lyn →
43 Lyn →, →
44 Lyn →
α Lyr →
β Lyr →, →, →
γ Lyr →
ε Lyr →, →, →, →, →, →, →, →
ζ Lyr →
η Lyr →, →
θ Lyr →
4 Lyr →
5 Lyr →
β Mon →
γ Mon →
ε Mon →
ζ Mon →
3 Mon →
9 Mon →
10 Mon →, →
11 Mon →
12 Mon →, →, →
15 Mon →, →, →, →
16 Mon →
17 Mon →
R Mon →
RY Mon →, →
α Oph →

β Oph →
δ Oph →
λ Oph →
ρ Oph →, →, →, →, →, →, →
21 Oph →
22 Oph →
51 Oph →
70 Oph →, →
72 Oph →
α Ori →, →, →
β Ori →, →, →, →
δ Ori →
ε Ori →, →, →, →
ζ Ori →, →
θ Ori →, →, →, →, →, →, →, →, →
ι Ori →, →, →
κ Ori →
λ Ori →
ν Ori →, →
ξ Ori →
ρ Ori →
σ Ori →, →, →
29 Ori →
42 Ori →, →, →
55 Ori →, →
BL Ori →, →, →
V380 Ori →
W Ori →
α Peg →
γ Peg →
57 Peg →
69 Peg →
82 Peg →, →
α Per →
β Per →, →
ε Per →
κ Per →
ο Per →, →, →
ε Per →, →, →, →, →
h Per →, →

36 Per →
41 Per →
53 Per →
V466 Per →, →
V747 Per →
α PsA →, →, →
ε PsA →, →
ι PsA →, →, →
16 Psc →
19 Psc →, →
47 Psc →
70 Psc →
TX Psc →, →
κ Pup →
ξ Pup →
ρ Pup →, →
2 Pup →, →, →, →
4 Pup →
6 Pup →
16 Pup →, →, →
19 Pup →, →, →
19 Pyx →
α Sco →, →
ο Sco →, →
ρ Sco →
σ Sco →
19 Sco →
22 Sco →
β Sct →
η Sct →, →
R Sct →
α Ser →
δ Ser →
θ Ser →
σ Ser →
18 Sge →
β Sgr →
ζ Sgr →
ν Sgr →
ν1 Sgr →, →

ν2 Sgr	→, →, →
3 Sgr	→
9 Sgr	→, →
11 Sgr	→
13 Sgr	→
43 Sgr	→, →, →
63 Sgr	→
α Tau	→
β Tau	→, →
ζ Tau	→, →, →, →
τ Tau	→
20 Tau	→
34 Tau	→
119 Tau	→
132 Tau	→
CE Tau	→
δ UMa	→
ε UMa	→
ζ UMa	→, →, →, →
θ UMa	→
λ UMa	→
μ UMa	→, →
ξ UMa	→, →
ο UMa	→
π1 UMa	→
σ2 UMa	→
υ UMa	→, →, →
27 UMa	→
70 UMa	→, →
73 UMa	→
α UMi	→, →, →
β UMi	→, →
γ UMi	→
ε UMi	→
ζ UMi	→
8 UMi	→
11 UMi	→
α Vir	→
β Vir	→, →
γ Vir	→, →, →

δ Vir →
ε Vir →
θ Vir →, →
ξ1 Vir →
ρ Vir →
υ1 Vir →
ψ Vir →
34 Vir →
39 Vir →
40 Vir →
71 Vir →
72 Vir →
92 Vir →
FT Vir →
7 Vul →
12 Vul →
20 Vul →

Stars: catalogues

Groombridge 1830 →
HD 3293 →
HD 3411 →
HD 144463 →
HR 3932 →
HR 5633 →
HR 6237 →
LL 22369 →
LL 40765 →
Mayer 420 →
Mayer 510 →
Mayer 522 →
O170 →, →
O209 →
O408 →
SAO 2556 →
SAO 6948 →, →
SAO 7194 →, →
SAO 7497 →
SAO 7500 →

SAO 7513 →
SAO 7521 →
SAO 7522 →
SAO 14654 →
SAO 77598 →
SAO 204955 →
Σ 131 →
U1 →
U2 →
U13 →
U27 →
U138 →
U203 →, →
U214 →
U215 →
U220 →, →
U237 →
U243 →
U327 →, →
U379 →
U398 →, →
U422 →
U440 →, →
U450 →, →
U472 →
U473 →
U474 →
U637 →
U657 →, →
U727 →
U760 →
U787 →
U794 →, →
U809 →
U817 →
U871 →
U872 →
U938 →
U939 →
U976 →, →

U1018 →
U1019 →
U1022 →
U1023 →
U1024 →
U1025 →
U1040 →, →
U1096 →
U1097 →
U1098 →
U1107 →
Winnecke 4 →, →

Solar System

Ariel →
Ceres →, →, →, →, →, →, →, →, →, →
Comet 1702 →
Comet 1779 →
Comet 1783 →, →
Comet 1799 →
Comet 1807 →, →, →
Comet 1811 →, →, →, →, →
Comet 1819 →, →, →
Comet 1823 →
Comet Biela →, →
Comet C. Herschel 1 →, →
Comet C. Herschel 2 →, →
Comet C. Herschel 3 →, →
Comet C. Herschel 4 →, →
Comet C. Herschel 5 →
Comet C. Herschel 6 →, →
Comet C. Herschel 7 →, →
Comet C. Herschel 8 →
Comet Encke →
Comet Gregory →, →
Comet Halley →, →, →
Comet Méchain →, →
Comet Messier →, →
Comet Olbers →, →

Comet Pigott →, →, →
Comet Pons →, →, →
Comet Tralles →, →
Earth →, →, →
Enceladus →, →, →, →, →, →
Galilean moons →
Georgian planet →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Georgian satellites →, →
Georgium Sidus →, →, →, →, →
Juno →, →, →, →, →, →
Jupiter →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Leonid →
Mars →, →, →, →, →, →, →, →, →, →, →
Mercury →, →, →, →, →
Mimas →, →, →, →, →
Moon →, →
Neptune →, →
Oberon →, →, →, →
Pallas →, →, →, →, →, →, →, →
Perseid →
Pluto →
Saturn →, →–→, →, →, →, →, →, →, →, →, →, →
Sun →, →
Titania →, →, →, →
Umbriel →
Uranus →, →, →, →, →, →, →–→, →, →, →, →, →, →, →, →, →, →, →,

→, →, →, →–→, →, →, →, →,
→, →, →, →, →, →, →, →, →,
→, →, →, →, →, →, →, →, →,
→, →, →, →, →, →
Uranus rings →, →
Venus →, →, →, →, →, →, →, →, →, →, →
Vesta →, →, →, →, →, →, →

Subjects

General

Page numbers of object categories, like ‘open cluster’, do not refer to individual objects, but to general contexts; exceptions are figures or in some cases tables.

52 regions →, →
abbreviation (AR) →
abbreviation (description) →, →, →
abbreviation (p, f) →
abbreviation (type) →
aberration →, →, →, →
absorption →, →, →, →
absorption lane →, →, →, →
accuracy (catalogue) →
accuracy (position) →, →, →, →, →, →, →, →
achromatic →, →
adaptation →, →, →, →, →, →
affected region →, →, →, →, →
air pollution →
almanac →, →
alt-azimuthal →, →, →, →
ambiguous object →
annual observations →, →, →
annular galaxy →
annular nebula →, →, →, →, →, →
aperture →, →, →, →
aperture ratio →, →, →
asterism →, →, →, →, →, →, →, →, →, →,

→, →
asteroid →, →, →, →, →, →, →
astrometry →, →
astronomer (amateur) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
astronomer (professional) →, →, →
Astronomer Royal (fifth) →, →, →, →, →, →
Astronomer Royal (first) →, →, →, →, →, →
Astronomer Royal (third) →
Astronomer Royal for Ireland →, →
Astronomer Royal for Scotland →
astronomical regulator →
Astronomical Unit →
asymmetric galaxy →, →, →
asymmetric nebula →
asymmetric nucleus →, →
atmosphere (Earth) →, →
atmosphere (nebulous) →, →, →, →, →, →, →, →, →, →, →, →
atmosphere (refraction) →
atmosphere (Sun) →, →
aurora →, →, →, →, →, →
axis ratio →
bar (index) →, →, →, →
bar (mechanism) →, →, →, →, →, →
bar (motion) →, →, →
bar (table) →, →
barred spiral galaxy →, →, →, →, →, →, →, →
Bayer letter →, →, →, →, →, →, →, →
bell (mechanism) →, →, →, →, →, →, →, →
bifurcated (nebula) →, →, →
binary system →
binocular →, →, →, →
bipolar (nebula) →, →, →, →, →
blunder →, →, →, →
border-gage →
branch (cluster) →, →
branch (description) →
branch (nebula) →, →, →, →, →, →, →, →, →, →,

→, →, →, →, →, →, →, →, →, →, →
branch (stratum) →, →, →, →, →, →
brightest stars →, →
brightness →
brightness class →, →
brightness distribution →
brightness scale →, →, →
brush →, →, →, →, →, →, →, →, →, →, →
bubble (level) →, →
bulge →
candlelight →, →, →, →, →
Cape observations →, →
Carbon star →
Caroline (accident) →, →, →, →, →
Caroline (blindness) →
Caroline (comet) →, →
Caroline (cottage) →, →, →, →, →, →, →, →
Caroline (observatory) →, →, →
Caroline (sweeping) →
celestial angles →
celestial equator →, →, →, →
central star →, →, →, →, →, →, →, →
central star (PN) →, →, →, →, →, →, →, →, →, →, →, →, →
Cepheid →
chevelure →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
class designation →, →, →, →, →, →, →, →, →
classification →, →, →, →, →, →, →, →, →, →
classification (Hubble) →
classification (Wolf) →
clothing →
clouds →, →, →, →, →, →, →, →, →, →, →
cloudy star →, →, →, →, →, →, →, →
cluster chain →, →
Coat of Arms →, →
cocus wood →, →

cold night →, →, →, →

cold winter →

colour (nebula) →

colour (planet) →, →, →

colour (PN) →, →, →, →, →

colour (red cluster) →, →, →, →, →

colour (red nebula) →

colour (red star) →, →–→, →, →, →, →, →, →, →, →, →, →, →, →, →, →

colour (ruby red star) →

colour (star) →, →, →, →, →, →, →, →, →, →, →, →

colour index →, →, →, →, →

cometary (galaxy) →, →, →

cometary (nebula) →, →, →, →, →

cometic →, →, →, →, →, →, →, →, →, →

comet-seeker →

comet (supposed) →–→, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →

compact group →, →

concentration class →, →

constellation →, →

constellation (old) →, →, →, →, →, →

constellation (southern) →, →, →, →, →, →

construction of the heavens →, →

contact pair →, →, →

cool out (mirror) →

coordinate (Auwers) →, →, →

coordinate (equatorial) →, →, →, →, →, →, →, →, →, →, →, →–→, →, →, →, →, →, →

coordinate (galactic) →

coordinate (J. Herschel) →

coordinate (Messier) →, →, →

coordinate (sweep area) →, →

Copley Medal (William) →, →

coverage (sky) →, →, →, →, →

coverage (sweep) →, →
crosshair →, →, →, →
dark lane →, →, →, →, →, →
dark nebula →, →, →, →, →, →
dark structure →, →, →, →
darkening glass →
daylight →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
deception →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
deep-sky catalogue →
deep-sky discovery →, →, →, →
deep-sky object →, →, →, →, →, →, →, →, →, →, →, →
demonstration sweep →
dew →, →
diffused milky nebulosity →, →, →, →
disk (galaxy) →, →, →
disk (nebula) →
disk (planet) →, →, →, →
disk (Sun) →, →
distance (angular) →, →
distance (cosmic) →, →, →, →, →, →, →, →, →, →, →, →, →, →–→, →, →, →, →, →, →, →
distance-gage →
double eye glass →, →, →, →, →, →, →
double galaxy →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
double nebula →, →, →, →, →, →, →, →, →, →, →, →, →, →
double star →, →
double star (class) →, →, →
double star (John) →
double star (naked eye) →
double star (orbital motion) →, →, →, →, →

drawing →, →
dumbbell galaxy →, →
dust cloud →, →
dwarf galaxy →
earthquake →, →
eastern sweep →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
eclipse (lunar) →, →, →, →, →, →
eclipse (solar) →, →, →, →, →, →, →, →, →, →
ecliptic →, →, →, →
ecliptic (pole) →
ecliptic (Register) →
ecliptic (Review) →, →, →, →, →
ecliptic (sweep) →, →, →, →, →, →, 799
edge-on (galaxy) →, →, →, →, →, →, →, →, →, →
edge-on (Saturn) →, →
Effusion →
elevation →, →, →, →, →, →, →, →, →, →, →, →, →, →
elevation (40-ft) →
elevation (high) →, →, →, →, →, →, →, →, →, →, →, →
elevation (low) →, →, →, →, →, →, →, →, →
elongated (cluster) →, →, →, →
elongated (nebula) →, →, →, →, →, →, →, →
emission nebula →, →, →, →, →, →, →, →, →, →, →, →
Encke division →
entrance pupil →, →
epitaph →
equatorial →, →, →, →, →, →, →, →, →, →

equinox (1659) →
equinox (1660) →
equinox (1690) →, →, →, →, →, →, →, →, →
equinox (1790) →
equinox (1800) →, →
equinox (1801) →, →, →
equinox (1830) →, →, →
equinox (change) →, →, →, →
equinox (date) →, →, →, →, →, →, →, →, →, →
equinox (standard) →, →
error (Flamsteed) →
error (Herschel's) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
error (Messier) →, →
exit pupil →, →
extensions →, →
extensive diffused nebulosity →, →, →, →, →, →, →, →, →, →, →
eye-piece (40-ft) →, →, →
eye-piece (collection) →, →, →
eye-piece (double) →, →, →, →, →, →, →
eye-piece (exit pupil) →
eye-piece (holder) →, →
eye-piece (micrometer) →, →, →
eye-piece (No. 2) →
eye-piece (No. 4) →, →, →
eye-piece (No. 5) →, →
eye-piece (No. 8) →
eye-piece (position) →, →, →, →, →, →, →, →
eye-piece (slider) →, →, →, →, →
eye-piece (standard) →, →, →, →, →, →, →
eye-piece (X-foot) →, →, →
face-on →, →, →, →, →, →, →, →, →
fan-shaped →, →, →, →, →, →
field of view (20-ft) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
field of view (40-ft) →, →, →, →, →
field of view (7-ft) →
field of view (finder) →

field of view (gage) →, →, →, →
field of view (large sweeper) →, →
field of view (night glass) →
field of view (small sweeper) →, →, →
field of view (sweep) →, →
field orientation →, →, →, →
field sweeping →
filter →
Flamsteed number →, →, →, →, →, →, →, →, →, →, →, →, →
flat galaxy →, →, →, →, →, →, →, →, →, →, →
flattening (Uranus) →
Fluvius Aquarius →
focal length →, →, →, →, →, →, →, →
fog →
following / preceding →
Form (I–V) →, →, →
frost →, →, →, →, →
Galactic Anti-Centre →, →, →
Galactic Centre →, →, →, →
galactic equator →, →, →, →
galactic halo →
galactic latitude →, →, →, →, →
galactic nebula →, →, →
galaxy chain →, →
galaxy cluster →, →, →, →, →, →, →, →, →, →
galaxy group →, →, →, →, →
galaxy quartet →, →, →, →, →, →
galaxy quintet →
galaxy sextet →, →, →, →
galaxy trio →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
gallery →, →–→, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
gallery (40-ft) →, →

gallery (crash) →, →, →
garnet star →, →, →, →, →, →, →, →, →, →, →, →, →
General number →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
giant elliptical galaxy →, →
glass mirror →
glass window →
globular cluster →, →, →, →, →, →, →, →
globular cluster (40-ft) →
globular cluster (colour) →
globular cluster (concentration class) →
globular cluster (distance) →, →, →
globular cluster (form) →, →, →, →
globular cluster (resolved) →
Gold Medal (Caroline) →, →, →, →, →, →, →
grand design galaxy →
grant (40-ft) →, →, →
gravitation →, →, →, →, →
great motion →, →, →, →
Greenwich Mean Time →, →, →, →, →, →, →
Guelphic Order →, →, →
half field (HF) →, →
half swept →, →, →, →, →, →, →, →, →
haze →, →, →, →, →, →, →
haziness →, →, →, →, →, →, →, →, →, →, →, →
heat →, →
Herschel 2500 →
Herschel 400 →
Herschel bust →, →
Herschel manuscript (H.MS.) →, →
Herschel mounting →
Herschel object designation →
Herschel omitted nebulae (HON) →, →
Herschel wedge →
Herschel's ray-function →, →
Herschel's section →, →, →, →–→, →, →, →
high power →, →, →, →, →, →, →, →

HII-region →, →, →, →, →, →, →, →, →, →, →, →
‘hole’ (vacant region) →, →, →
honorary doctor (LL.D.) →, →, →, →
honorary member →
Honores Friderici →
hood (dark adaption) →
hot star →
hurricane →, →
hydrogen →, →
identity (catalogue entries) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
illusion →, →, →, →
inclination →, →
index scale →, →
infrared →, →, →
inhabited Moon →
interstellar matter →, →, →
iris →, →, →
irregular cluster →, →, →, →
irregular galaxy →, →, →, →, →, →
irregular nebula →, →
ladder →, →, →, →, →, →, →, →, →
lateral motion →, →, →, →, →, →, →
Latin →, →, →, →
lens →, →, →, →, →, →, →, →, →
lenticular galaxy →, →, →, →
light pollution →, →
line of sight →, →, →, →
Lucid spot →, →, →
luminous matter →
lunar phase →, →
Lynx error →
magellanic galaxy →, →, →, →
magnification →, →, →, →, →, →
magnitude →, →, →, →, →–→, →
Mercury transit →, →, →, →, →, →, →

meridian →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
meridian circle →, →
meridian passage →, →, →, →, →, →
Messier marathon →, →
Messier objects →, →, →, →
meteor →, →, →, →
micrometer →, →, →, →, →, →, →, →, →, →
milky nebulosity →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
minor planet →, →, →, →
mirror →
mirror (casting) →, →, →, →, →, →
mirror (cooling) →
mirror (cracked) →
mirror (deformation) →
mirror (metal) →, →, →, →, →
mirror (new) →, →, →, →
mirror (polishing) →, →, →, →, →, →, →, →, →, →
mirror (secondary) →, →, →, →, →
mirror (tarnished) →, →, →, →, →
mirror (tilted) →, →
mirror (weight) →, →
missed nebulae →
missing object →, →, →, →, →, →, →, →, →, →, →, →, →
missing star →
modern object types →, →
moisture →, →, →, →
Monkey Clock →
moonlight →, →, →, →, →, →, →, →, →, →, →, →, →
morphology →, →, →
motion (20-ft) →
mottled →, →, →, →, →, →, →, →, →
mountain (Moon) →, →
multiple nebula →, →, →, →
multiple nucleus →
multiple star →, →, →, →, →, →, →–→, →, →,

→, →, →, →, →, →, →, →
multiplier →, →
music →, →, →, →, →
mystery sweep (1096) →, →
naked eye →, →
naturalized →, →
nebulae quartet →, →
nebulae trio →, →
Nebulosæ →, →
nebulous star →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
nebulous stars (publication) →, →, →, →, →, →, →, →, →, →, →
nitrogen →
non-stellar objects →, →
non-stellar objects (brightness) →, →
non-stellar objects (catalogue) →, →, →, →, →, →, →, →, →
non-stellar objects (classification) →
non-stellar objects (colour) →
non-stellar objects (discovered) →, →, →
non-stellar objects (distance) →, →
non-stellar objects (identification) →
non-stellar objects (individual) →
non-stellar objects (missed) →
non-stellar objects (true) →, →
non-stellar objects (types) →
non-stellar objects (visible) →
North Galactic Pole →, →, →, →
north pole →, →
northern sweep (above the pole) →, →, →, →, →, →, →, →, →, →–→, →, →, →, →, →, →, →, →, →, →, →, →
northern sweep (under the pole) →, →, →, →, →, →, →, →, →, →, →, →
not registered (sweep) →, →, →, →, →, →, →, →, →, →

Nova (nebula) →, →, →, →
Nova (star) →, →, →
observing chair →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
observing session →, →, →, →, →, →, →, →, →, →
offset (position) →, →, →, →, →
omitted star →, →, →, →, →, →
open cluster →, →
optical pair (galaxies) →, →
optical pair (stars) →, →, →, →, →, →
orbital motion (Earth) →
orbital motion (globular cluster) →
orbital motion (moons) →
orbital motion (planet) →, →, →, →
orbital motion (PN ‘satellite’) →
Ordnance map →
orientation (field of view) →, →, →, →, →, →, →, →
orientation (galaxies) →, →
orientation (Milky Way section) →, →
orientation (telescope) →
oscillation →–→, →–→, →, →, →, →
oxygen →, →
parallax →, →, →, →, →, →, →, →, →, →, →, →, →
part of galaxy →, →, →
patch →, →, →, →, →, →, →, →–→, →
PD clock →, →, →, →, →, →, →, →, →, →, →
PD index →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
PD string →, →, →, →, →, →, →, →, →
PD zones →, →, →, →, →, →, →, →
pendulum clock →, →, →, →, →
photography →, →, →, →, →, →, →, →

planet →, →, →, →
planetary nebula →, →
planetary nebula (class) →, →, →, →, →, →, →, →
planetary nebula (colour) →
planetary nebula (physical) →, →, →
planetary nebula (‘satellite’) →, →
planetule →
polar coordinates →
Polar Distance (PD) →, →
polar region →, →, →, →
position (absolute) →, →, →, →, →, →, →, →
position (relative) →, →, →, →, →, →, →, →, →, →, →, →
position angle →, →, →, →, →
precession →, →, →, →, →, →, →, →
preceding / following →
prism →, →
prismatic experiment prismatic power (atmosphere) →, →, → →
profundity →, →, →, →, →, →
projection (Mollweide) →
projection (plane) →, →, →
projection (polar) →
projection (rectangular) →, →
projection (sphere) →
proper motion →, →, →, →, →, →, →–→
quadrant →, →, →, →, →, →, →, →, →, →
quadruple nebula →, →
quasar →
rain →, →
ray (comet) →
ray (lucid) →
ray (milky) →, →, →, →, →, →, →, →
ray (of light) →, →, →
ray (Saturn) →
ray (solar) →

ray (visual) →, →
red giant →, →
redshift →
reference star →, →–→, →, →, →, →, →, →, →, →
reflection nebula →, →, →, →, →, →, →, →, →, →, →, →
refraction (atmosphere) →
Register sheet →, →
requiem →
resolvable (abbreviation) →
resolvable globular cluster →
resolvable nebula →, →, →, →, →–→, →–→, →, →, →, →
resolved (Milky Way) →, →
resolved globular cluster →, →, →
resolved nebula →, →, →, →, →, →
retina →
Right ascension (AR) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
ring nebula (M 51) →, →
round motion →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Royal Astronomer →
scintillation →
seeing →, →
separation class →, →, →
setting circles →
sextuple nebula →, →
side motion →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
side view (edge-on) →
side view (Newtonian) →
sidereal clock →, →, →, →, →, →, →, →, →
sidereal time →, →, →, →, →, →, →, →, →, →, →, →, →, →
Sirius-Weiten →

Sir William →, →, →, →, →, →, →, →, →, →, →, →, →
size class →
sketch (Caroline) →, →, →, →, →, →, →, →
sketch (other) →, →, →, →
sketch (position) →, →, →, →, →, →, →, →, →, →, →
sketch (William) →, →–→, →
sky coverage →, →, →, →, →
sky motion →, →, →, →, →, →, →, →
Slough observations (John) →, →, →, →, →, →
snow →, →
solar apex →, →, →, →
solar motion →, →
South Galactic Pole →, →, →
space-penetrating power →, →, →, →, →, →, →, →, →, →
speaking pipe →, →
spectroscope →, →
spectrum →, →, →, →, →
speculum →, →
spiral arms →, →, →, →, →, →, →, →, →, →, →
spiral galaxy →, →, →, →, →, →, →, →, →, →, →
spiral nebula →, →, →, →
spiral structure →, →, →, →, →, →, →, →
standardized description →, →, →, →
star chain →, →, →, →, →, →
star cluster →, →
star density →, →, →, →, →, →, →, →

star gage →, →
star group →, →, →, →, →, →, →, →, →, →
star party →, →, →
star quartet →, →, →
star review →, →, →, →, →, →, →, →, →, →, →
star review (first) →, →
star review (second) →, →, →
star review (third) →, →
star-hopping →, →, →
star-light weather →
stellar nebula →, →, →, →, →
stellar statistics →, →, →
storm →, →
strangulation →, →
stratum (bifurcated) →, →
stratum (double) →, →
stratum of Coma Berenices →, →, →, →, →, →, →, →, →, →, →, →
stratum of stars →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
stray light →, →, →, →
subjectivity →
sunspot →, →, →
sunspot (opening) →
super star cluster →, →, →
superimposed galaxy →
superimposed star →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
supernova →, →, →, →
supernova remnant →, →, →
superthin galaxy →, →
surface (Sun) →, →
surface brightness →, →, →, →, →, →, →, →, →, →, →, →
suspected object →, →
Sütterlin →, →
sweep (40-ft) →, →

sweep area →, →, →
sweep areas →, →, →
sweep areas (overlap) →, →, →
sweep list →, →, →
sweep path →, →, →, →
sweep pattern →, →, →, →
sweep plan →, →
sweep records (Fixt Stars) →, →, →, →
sweep records (Journal) →, →, →, →, →
sweep records (‘Original’) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
sweep records (revision) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
sweep speed →, →, →, →, →, →, →, →, →
sweep stop →, →, →
sweeping motion →, →, →, →, →, →, →, →, →, →, →, →, →, →
telescope design →, →
Telescopium Herschelii →
temperature →, →, →, →
thermal radiation →, →, →, →
thermometer →, →, →
tracking →, →, →, →, →, →, →, →, →, →
transit instrument →, →, →, →
transparency →, →
treble nebula →
triangular wires →, →, →, →
Triangulum minor →
triple nebula →
Tubus Hershelli Major →
Tubus Hershelli Minor →
twilight →, →, →, →, →, →, →, →, →, →
typo →, →, →
uncatalogued object →, →, →, →, →, →, →–→, →, →, →, →
unknown star →, →, →, →, →, →, →, →, →, →, →
unresolvable globular cluster →
unresolvable nebula →, →
vacant place →, →, →, →, →, →, →, →, →–→,

→, →, →, →, →, →, →
variable star →, →, →, →, →, →, →
Venus transit →, →, →
viewing direction →, →
vignetting →
vision (averted, direct) →
visitor →, →, →, →, →, →, →
visitor (book) →, →
visitor (list) →, →
volcano (Moon) →, →
weather →, →
whitish nebulosity →, →, →
William Herschel (name versions) →
wind →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
wooden tube →, →
working list →, →
workman →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
workshop →, →, →
zenith →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
zodiacal Scorpion →
zodiacal star →
zone of avoidance →, →, →

Telescopes

1.5-ft refractor (Caroline) →, →
10-ft Gregorian reflector →
10-ft reflector →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
10-ft reflector (front-view) →, →
10-ft reflector (Göttingen) →, →
10-ft reflector (large) →, →, →
10-ft reflector (stopped) →
11¾-in refractor (South) →

11-in refractor (d’Arrest) →, →
12.5-in refractor (Bigourdan) →, →
12-in reflector →, →, →, →, →, →, →, →
12-in reflector (Hahn) →
12-in refractor (Lick) →
12-in reflector (St. Petersburg) →
14-in reflector (Glasgow) →
14-in reflector (Steinicke) →
15-in reflector (Ramage) →
16-in refractor (Hagen) →
18.6-in refractor (Safford) →
18.7-in reflector →, →, →–→, →, →, →, →, →, →, →, →, →
18¼-in (John) →, →, →, →, →, →, →, →, →, →, →, →
18-in quadrant →, →
20-ft (front-view) →, →
20-ft reflector →, →
20-ft reflector (large) →, →, →
20-ft reflector (small) →, →, →, →–→, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
20-ft reflector (St. Petersburg) →
23-ft refractor (Huygens) →
24-in reflector (Lassell) →
24-in reflector (Spanish telescope) →, →, →, →, →, →
24-in reflector (X-foot) →, →, →, →, →, →
24-in refractor (Arequipa) →
25-ft reflector →, →, →, →, →, →, →, →, →, →, →, →
25-ft reflector (stopping) →
26-in refractor (US Naval) →
29.5-in reflector (Mitchell) →
3.5-ft reflector →, →
3.5-ft refractor (Aubert) →
3.5-in refractor (Messier) →

3.7-in refractor (Webb) →
3.75-in refractor (South) →
30-ft reflector →, →, →
31-in reflector (Stephan) →
36-in reflector →, →, →
36-in reflector (Rosse) →
3-in refractor (Mayer) →
3-in refractor (Méchain) →
40 cm refractor (Wolf) →
4.2-in reflector (Caroline) →, →, →, →, →, →
4.5-in reflector →, →, →
4.5-in reflector (Caroline) →
40-ft reflector →, →–→, →, →
48-in reflector →, →, →, →
48-in reflector (Lassell) →
4-ft reflector →
4-ft refractor →
4-in reflector (7-ft) →, →, →, →, →
5.5-ft reflector →–→, →, →, →, →, →
5-in refractor (Barnard) →, →
5.9-in refractor (Smyth) →
6.2-in reflector →, →, →, →, →, →, →
6.5-in refractor (Lick) →
6-ft refractor (Greenwich) →
72-in reflector (Rosse) →, →, →, →, →, →, →, →, →, →, →, →, →, →
7-ft reflector →, →
7-ft reflector (4.5-in) →
7-ft reflector (Dresden) **569**
7-ft reflector (Hanover) →
7-ft reflector (skeleton) →, →
7-ft refractor (Flamsteed) →, →, →
7-in refractor (Hind) →
7.4-in refractor (Auwers) →
9-in Gregorian reflector →

9.6-in reflector (Caroline) →, →, →
9-in reflector →, →, →
achromatic refractor →, →, →, →, →, →, →, →, →, →, →, →
air refractor →
Bird quadrant →, →, →
Bruce refractor →
Byrne refractor →
Cassegrain →
Dobsonian →, →
Dolland refractor (3.5-ft) →, →, →, →, →
equatorial (reflector) →, →, →
equatorial (refractor) →, →, →
finder (10-ft) →
finder (20-ft) →, →, →, →, →, →, →, →, →, →, →, →, →, →
finder (7-ft) →, →, →, →, →
finder (small sweeper) →
Fraunhofer refractor →, →
front-view (10-ft) →
front-view (25-ft) →, →, →
front-view (40-ft) →, →, →, →, →, →
front-view (comparison) →, →, →, →
front-view (eye-piece) →
front-view (gage) →
front-view (invention) →
front-view (J. Herschel) →, →, →
front-view (observation) →, →, →, →, →, →, →
front-view (orientation) →, →
front-view (standard) →, →, →
front-view (test) →, →, →, →
front-view (visitor) →, →
Gregorian →, →, →, →
Hadley quadrant →
Herschelian →
Huygenian refractor →, →, →
large sweeper →, →, →, →, →, →, →, →, →, →, →, →, →
large sweeper (John) →
Leviathan of Parsonstown →

Merz refractor →, →, →
mural circle →, →, →
Newtonian →, →
night glass →, →, →, →
quadrant (T. Mayer) →
Short refractor →
skeleton reflector →, →
small sweeper →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Spanish telescope →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Tully refractor →, →, →
X-foot reflector →, →, →, →, →, →, →, →, →, →, →, →
Zeiss refractor →

Institutions and sites

(for important websites see References)

Arequipa Observatory →
Armagh Observatory →, →, →, →, →, →
Astronomical League →
Astronomical Society of London →, →, →, →, →
Astronomical Society of London (President) →, →, →, →
Bath →, →, →, →, →, →, →
Bath Philosophical Society →
Bath (Alexander) →, →, →, →, →, →, →
Bath (Caroline) →, →
Bath (Museum) →, →
Bath (visitor) →, →, →, →, →, →
Bedford Observatory →
Bedlam (London) →

Berlin →, →, →, →, →, →, →, →
Berlin Observatory →
Birmingham →, →
Birr Castle →, →, →, →, →, →, →–→, →, →, →, →, →, →, →, →, →, →, →, →–→, →, →
Bishop's observatory (London) →, →
Bonn Observatory →
Bremen →, →, →
Brera Observatory (Milan) →
Bristol →, →
British Astronomical Association →
Cambridge →, →
Cambridge University →, →, →
Cape (of Good Hope) →, →, →, →, →, →, →, →, →
Cape Town →, →, →, →
Cape Town University →
Church of St. Lawrence (Upton) →
Clay Hall →, →, →, →, →, →, →
Collegium Romanum Observatory →
Copenhagen y →, →, →, →
Datchet →, →, →, →, →, →, →, →, →, →, →, →, →
Deptford →
Deutsches Museum (München) →
Dresden →
Dorpat Observatory →, →
Dunsink Observatory →
Feldhausen →, →, →, →, →, →, →, →
Edinburgh →, →
Geneva University →
Glasgow →, →
Glasgow Observatory →, →
Glasgow University →, →, →, →, →
Göttingen →, →, →, →
Göttingen Observatory →, →, →, →, →, →
Göttingen University →, →
Greenwich →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Halifax →

Hanover →, →
Harry Ransom Center (Austin) →, →
Harvard →, →
Harvard (Houghton Library) →
Harvard College Observatory →, →, →, →
Herschel Museum (Bath) →, →, →
Herschel Society (Bath) →, →, →
Historisches Museum (Hannover) →
Hôtel de Cluny (Paris) →, →
Ireland →
Kew Gardens Observatory →, →, →, →
Kirby Hill →, →, →
Königsberg Observatory →, →, →, →
Königstuhl Observatory (Heidelberg) →, →
Kraków Observatory →, →
Leipzig Observatory →
Lick Observatory →
Lilienthal (Bremen) →, →, →
London →, →
Madison →
Madrid →
Madrid Observatory →, →
Malta →, →
Mannheim →, →, →
Mannheim Observatory →, →, →, →
Mathematisch-physikalischer Salon (Dresden) 569
Nashville →
National Portrait Gallery (London) →
Newbury →, →
Nice Observatory →
Observatory House (Slough) →
Old Windsor →, →, →, →
Oxford →, →
Oxford (Radcliffe Observatory) →, →

Oxford University →, →, →, →
Padua Observatory →
Palermo Observatory →, →, →
Palomar Observatory →
Paramatta →, →
Paris →, →, →, →, →, →, →, →, →, →
Paris Observatory →, →, →, →, →
Pulkovo Observatory (St. Petersburg) →, →
Remplin Castle →
Royal Astronomical Society →, →, →
Royal Astronomical Society (Caroline) →
Royal Astronomical Society (Herschel Archive) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Royal Astronomical Society (President) →
Royal Irish Academy →
Royal Observatory (Greenwich) →, →, →
Royal Observatory (Cape Town) →
Royal Society →, →, →, →, →, →, →, →
Royal Society (archive) →, →, →, →, →, →, →, →
Royal Society (Caroline) →, →, →, →
Royal Society (Curator) →
Royal Society (Fellow) →, →, →, →, →, →, →, →
Royal Society (gold medal) →
Royal Society (John) →, →, →
Royal Society (Librarian) →
Royal Society (paper sent/read) →, →
Royal Society (President) →, →, →, →
Royal Society (Secretary) →
Scotland →, →, →, →, →, →, →, →, →
Seeberg Observatory (Gotha) →, →, →
Slough →, →–→
Slough observatory →, →, →

St. Petersburg →
Starfield Observatory (Liverpool) →
Table Mountain →
Thames →, →, →
Thornhill →, →
Toulouse Observatory →
Trinity College →
U.S. Naval Observatory (Washington) →, →
Upton →, →, →, →
Vardø →
Vatican →
Vatican Observatory →, →, →
Wales →, →, →, →
Washburn Observatory (Madison) →
Webb Deep-Sky Society →
Wheatley →
Windsor Castle →, →, →, →
Yorkshire →, →

Sources, catalogues

(see also References)

Atlas Coelestis →, →
Atlas of Peculiar Galaxies (Arp) →, →
Autobiography (Caroline) →, →, →, →, →, →
Barnard's catalogue of dark nebulae (B) →, →
Bedford Catalogue →
Berliner Jahrbuch →, →, →
Bode's atlas →, →
Bode's catalogue →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Book of Observations →, →, →, →, →, →, →, →
British Association Catalogue →

(BAC)
British Catalogue →–→, →, →, →, →, →, →, →, →, →, →, →, →, →, →–→, →
British Catalogue (revision) →, →, →, →, →, →
Cape Catalogue →, →, →, →, →, →, →, →
Catalogue of 2500 Nebulae and Clusters →, →, →, →, →, →, →
Catalogue of comparative brightness →, →, →
Catalogue of double stars (first) →, →, →, →, →, →, →, →
Catalogue of double stars (second) →, →, →, →
Catalogue of double stars (third) →, →
Catalogue of nebulae and star clusters (first) →, →, →, →, →, →, →, →, →, →, →, →, →
Catalogue of nebulae and star clusters (revision) →, →, →, →, →, →
Catalogue of nebulae and star clusters (second) →, →, →, →, →, →
Catalogue of nebulae and star clusters (third) →, →, →, →
catalogue of omitted stars →, →, →, →
Catalogue of rich Clusters of Galaxies (Abell) →, →
Catalogue of Stars (Royal Society) →, →
Catalogue of the stars →, →, →, →, →, →
Catalogue of Zodiacal Stars →, →, →, →
Celestial Objects for Common Telescopes →
Coelum Australe Stelliferum →, →
Compact Groups of Galaxies (HCG) →
Connoissance (Connoissance) des Temps →, →
Cycle of Celestial Objects →
Die Herschel-Nebel →, →
Digitized Sky Survey (DSS) →

Edinburgh Philosophical Journal →
European Magazine →, →, →, →, →
Experiments on the construction of Specula →
Flamsteed-Fortin Atlas →
Fixt Stars →, →
GC supplement →, →
General catalogue (Caroline) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
General Catalogue (GC) →, →, →, →, →, →, →, →, →, →, →, →, →, →
Guide (software) →, →, →
Hamburgischer Correspondent →
Harris map →, →, →, →, →, →, →, →, →, →, →, →–→, →, →, →, →, →, →, →, →, →, →, →
Henry Draper Catalogue (HD) →
Herschel Archive →, →, →, →, →, →
Herschel catalogue of dark nebulae →, →
Histoire Céleste →, →, →, →
Historia Coelestis →, →, →, →
Index Catalogue (IC) →, →, →, →, →, →
Journal →, →
Journal (Caroline) →, →, →
List of Manuscripts →
Lynds Bright Nebula (LBN) →, →
Lynds Dark Nebula (LDN) →
Memoir and Correspondence of Caroline Herschel →, →, →, →, →, →
Memoires of the Royal Astronomical Society →
Memoires of the Astronomical Society of London →
Memorandum (William) →, →, →, →, →, →, →
Messier Catalogue (M) →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →

Messier Catalogue (first) →, →
Messier Catalogue (second) →, →, →, →, →, →, →, →
Messier Catalogue (final) →, →, →, →, →
Messier Catalogue (extended) →, →, →
Messier Catalogue (revised) →
Nautical Almanac →, →
New General Catalogue (NGC) →, →, →, →, →, →, →, →, →
Observations on the Georgian Planet and its satellites →
Observations with the 40-ft telescope →
Outlines of Astronomy →, →
Palomar Observatory Sky Survey (POSS) →, →, →
Philosophical Transactions (PT) →, →
Principia (Newton) →
Proceedings of the Royal Society →
Prodomus Astronomiae →
Register of double stars →, →
Register of Gages →, →, →, →, →, →, →, →, →
Register of Nebulae →, →, →
Register of Sweeps →, →, →, →, →, →, →, →, →, →, →, →
Review →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Scientific Papers →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Senex globes →
Senex map →, →, →
Siderum Nebulosorum Observationes Havnienses →, →
Simbad →
Sloan Digital Sky Survey (SDSS) →
Slough Catalogue →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Smithsonian Astrophysical Observatory Star Catalogue →

(SAO)
Synopsis (double stars) →
Temporary Index →, →, →, →, →, →, →, →, →
The Herschel Chronicle →, →
Treatise on Astronomy →
Uranographia →, →, →, →, →, →, →, →, →, →, →
Uranographia Britannica →
Uranometria →, →, →
Uranometria nova →
Verzeichnis neuer Nebelflecke →
Verzeichnisse von Nebelflecken und Sternhaufen →, →
Vorstellung der Gestirne →, →
Wollaston’s catalogue →, →, →, →, →, →, →, →, →, →, →, →, →, →, →
Yale Bright Star Catalogue (HR) →, →
Zone Catalogue (ZC) →, →
zone catalogue of stars (first) →, →, →, →, →, →, →, →, →
zone catalogue of stars (second) →, →, →, →

Abbreviations

(constellations are excluded; see also Table 2-36)

AR, α	right ascension
B	Barnard
BC	*British Catalogue*
B-V	colour index
CC	*Cape Catalogue*
Ced	Cederblad
CH	Caroline Herschel
Con, CON	constellation
Cr	Collinder
CS	central star
Decl, δ	declination
D	breadth

DG	Dorschner a. Gürtler
DS	double star
DSS	*Digitized Sky Survey*
E	elevation, East
EN	emission nebula
f	following (east)
FoV	field of view
FRAS	Fellow of the *Royal Astronomical Society*
FRS	Fellow of the *Royal Society*
ft	foot
GC	*General Catalogue*
GMT	Greenwich Mean Time
GN	General number
Gx	galaxy
GxP	galaxy part
H	W. Herschel object
h	J. Herschel object
H.MS.	Herschel manuscript
HCG	Hickson compact group
HD	*Henry Draper Catalogue*
HF	half field
HII	ionized hydrogen
HON	Herschel omitted nebula
HR	*Yale Bright Star Catalogue*
IC	*Index Catalogue*
in	inch
JH	John Herschel
LBN	Lynds dark nebula
LDN	Lynds bright nebula
LL	Lalande
LS	large sweeper
M	*Messier Catalogue*
mag	magnitude
MCG	*Morphological Catalogue of Galaxies*
Mel	Melotte
ms	manuscript
Mrk	Markarian
N, n	north
NF	not found

NGC	*New General Catalogue*
NGP	North Galactic Pole
O	omitted star
OC	open cluster
p	preceding (west)
PA	position angle
PD	polar distance
PN	planetary nebula
POSS	*Palomar Observatory Sky Survey*
PT	*Philosophical Transactions of the Royal Society*
Q	quadrant
R	AR range
RAS	*Royal Astronomical Society*
RN	reflection nebula
RS	*Royal Society*
S, s	south
SAO	*Smithonian Astrophysical Observatory Star Catalogue*
SC	*Slough Catalogue*
SGP	South Galactic Pole
SP	*Scientific Papers of Sir William Herschel*
SS	small sweeper
ST	sidereal time
sw	sweep
Tr	Trumpler
U	unknown star
UGC	*Upsala General Catalogue of Galaxies*
V	visual magnitude
vdB	van den Bergh
W	west
WH	William Herschel
ZC	*Zone Catalogue*
*	star

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DSO	*Deep-Sky Observer*
JAHH	*Journal of Astronomical History and Heritage*
JHA	*Journal for the History of Astronomy*
Mem. RAS	*Memoirs of the Royal Astronomical Society*
MN	*Monthly Notices of the Royal Astronomical Society*
PT	*Philosophical Transactions of the Royal Society*

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Herschel portrait (oil on wood), made by Antoine Coutel (1881); the 40-ft is seen in the background.

About the author

Dr Wolfgang Steinicke started his astronomical career with visual deep-sky observations, made with telescopes up to 20 inches aperture. To understand the theoretical background, he studied physics and mathematics in Germany, later specializing in Astrophysics, General Relativity and Quantum Mechanics. His astronomical interest later focused on Dreyer's *New General Catalogue* (NGC), which is largely based on observations by William and John Herschel. Research on non-stellar objects, their data and historical sources has led to extensive catalogues, including a revision of the NGC and its supplements. In 2008, he obtained a doctorate from the University of Hamburg with a dissertation on 19th-century deep-sky observations, which was published by Cambridge University Press in 2010 as 'Observing and Cataloguing Nebulae and Star Clusters: From Herschel to Dreyer's New General Catalogue'. Steinicke is a Fellow of the *Royal Astronomical Society*, Director of the History of Astronomy Section of the German

Vereinigung der Sternfreunde (Association of Amateur Astronomers), committee member of the British *Webb Deep-Sky Society*, member of the *Herschel Society*, Bath, and works for international associations. He frequently organizes astronomy meetings and gives lectures all over the world. Steinicke is the author of ten books (in German and English) and has published more than 300 scientific papers.

www.klima-luft.de/steinicke (latest versions of important historic and modern deep-sky catalogues)

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The author at a 7-ft Herschel reflector, exhibited in the Mathematisch-physikalischer Salon, Dresden.

Front cover: Herschel and his 20-foot Newtonian reflector, erected at Datchet in October 1783 (historic drawing modified by the author).

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